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Bethesda, Md. 20084

A FORTRAN IV COMPUTER PROGRAM FOR THE TIME DOMAIN ANALYSIS OF THE TWO-DIMENSIONAL DYNAMIC MOTIONS OF GENERAL BUOY-CABLE-BODY SYSTEMS

by

Henry T. Wang

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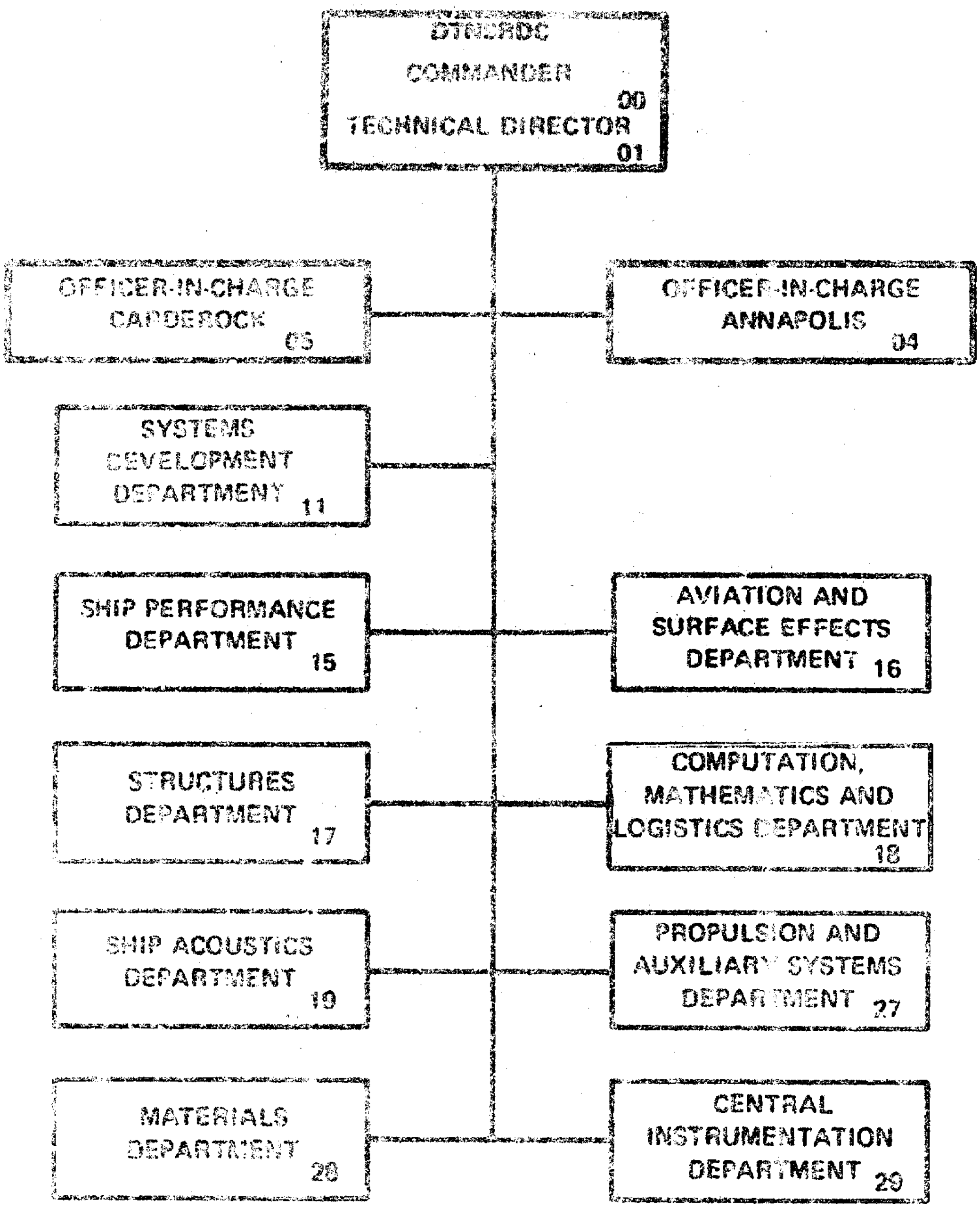

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The present report gives a detailed description of Program CABUOY which analyzes in the time domain the two-dimensional dynamic behavior of general ocean cable systems consisting of a surface buoy, connecting cable, and intermediate bodies. The equations which model the motions of the surface waves and the various components of the cable system are presented, and the subroutines of the program are briefly outlined. Instructions on use of the program include a listing of the input READ statements, definitions of the input variables, and a number of comments on the entering of input data. Several sample problems are given to illustrate use of the program, the output of the program, and computer costs for a range of cases. The listing of the program is given in the appendix.

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ABSTRACT

The present report gives a detailed description of Program CABUOY, which analyzes in the time domain the two dimensional dynamic behavior of general ocean cable systems consisting of a surface buoy, connecting cable, and intermediate bodies. The equations which model the motions of the surface waves and the various components of the cable system are presented, and the subroutines of the program are briefly outlined. Instructions on use of the program include a listing of the input READ statements, definitions of the input variables, and a number of comments on the entering of input data. Several sample problems are given to illustrate use of the program, the output of the program, and computer costs for a range of cases. The listing of the program is given in the appendix.

ADMINISTRATIVE INFORMATION

The work described in this report was authorized by the Naval Air Development Center under Project Orders 4-0601 and 0-0611 respectively dated 5 March 1974 and 13 February 1976. The work was performed under internal Work Units 1-1552-120 and 1-1552-145.

INTRODUCTION

The dynamic motion characteristics of cable systems are currently of extreme interest, and several major surveys of cable dynamics studies have been made in recent years [1-3]

An ocean cable system generally consists of the following three components:

1. A ship or surface float at the upper end.
2. A cable whose properties may vary along its length.
3. Intermediate bodies along the cable, including the possibility of a body at the lower end.

Previous studies have usually focused on only one of the above components. For example, the principal emphasis in many studies is on the dynamic characteristics of the cable itself.

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[1] Dillon, D.B., "An Inventory of Current Mathematical Models of Scientific Data - Gathering Moors," Hydrospace-Challenger, Inc. TR 4450 0001 (Feb 1973).
A complete list of references is given on pages 61-63.

[2] Choo, Y.I. and M.J. Casarella, "A Survey of Analytical Methods for Dynamic Simulation of Cable-Body Systems," Journal of Hydronautics, Vol. 7, No. 4, pp. 137-144 (Oct 1973).

[3] Albertsen, N.D., "A Survey of Techniques for the Analysis and Design of Submerged Mooring Systems," Civil Engineering Laboratory Technical Report R-815 (Aug 1974).

Conditions at the ends of the cable are then either those of prescribed motions or simple representations of the surface buoy or lower body. It appears that such studies were carried out mainly to demonstrate the feasibility of a particular method of solving for the dynamic characteristics of the cable. Choo and Casarella[2] discuss the merits and drawbacks of the three principal analytical methods: linearized frequency-domain method, method of characteristics, and finite element method. In other studies, the principal emphasis is on the dynamic characteristics of the surface buoy or the lower body and the effect of the cable is then approximated in various ways It is clear that these studies are suitable only for analyzing particular types of cable systems, also, only the dynamic characteristics of certain components are accurately described.

The present report gives details on Program CABUOY, which analyzes in the time domain the two-dimensional dynamic behavior of all three components of a general cable system. This program has already been briefly described.[4] Although it was developed principally to analyze the dynamic behavior of sonobuoy systems, for which it is of interest to know the dynamic behavior of the surface buoy, connecting cable, and lower acoustic detection units, the great generality and versatility of the program make it useful for a wide variety of other cable systems.

The report first presents in detail the equations which form the basis of the program. These include equations for the steady-state cable configuration and for the dynamic motions of the surface waves, surface buoy, cable, and intermediate bodies. Each of the program subroutines is briefly described. Detailed input instructions include a listing of the input FORTRAN READ statements, definition of the input variables contained in these READ statements, and comments on the entry of input data. Several sample problems serve to illustrate program use, output, and computer costs. The program is listed in the appendix.

Both the input instructions and the sample problems illustrate the wide applicability of the program. The sample problems range from a parametric study of the accuracy and computer cost of various finite element representations of the cable to the analysis of a complete buoy-cable-body system moored in the presence of typical ocean waves and current profiles. The characteristics of each component of the ocean surface waves may be specified by the user or may be internally generated by the program by means of the Pierson-Moskowitz spectrum. The surface buoy at the top of the cable may have a relatively wide range of sizes and shapes. It may be a prolate or oblate spheroid of any aspect ratio provided its horizontal

[4]Wang, H.T., "Preliminary Report on a Fortran IV Computer Program for the Two-Dimensional Dynamic Behavior of General Ocean Cable Systems," DTNSRDC Departmental Report SPD-633-01 (Aug 1975).

length is small compared to the wavelengths of the significant ocean waves, or it may be a spar buoy of any size. The reasons for these particular choices of buoy shapes and sizes are given in the section on surface buoys. Alternatively, motions may be prescribed at the upper end. The user determines the accuracy and computer cost of the dynamic analysis of the cable by specifying the total number of cable segments as well as the length of each segment. Several different formulations are given for the added masses and drag coefficients of the intermediate bodies.

STEADY-STATE CALCULATIONS

CABLE EQUATIONS

The program first calculates the configuration of the cable system in the presence of a steady-state current* alone, in the absence of any time-dependent excitations. The differential equations for the steady-state configuration of the cable are well known and take the following form for the coordinate system shown in Figure 1; for example, see Springston.[5]

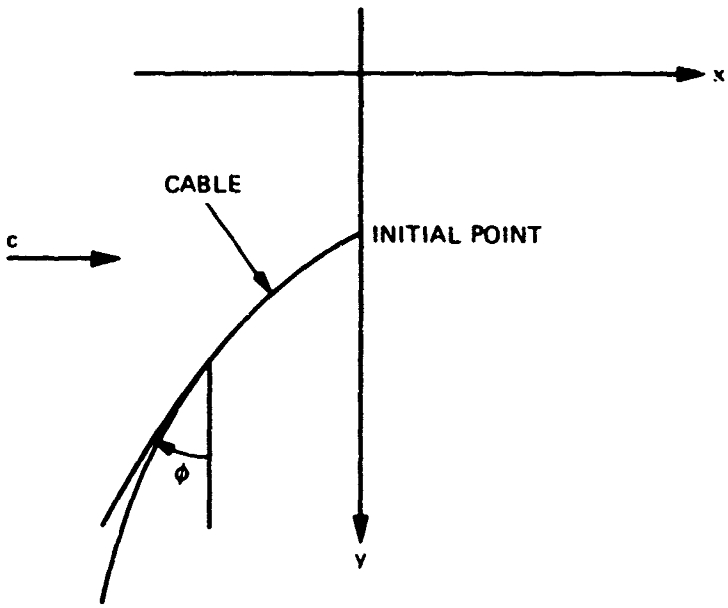

Figure 1 – Definition of Coordinate System

*The term current is used to denote the steady-state fluid velocity relative to the cable. For the case of a cable towed in still water, the current has magnitude equal to and direction opposite to the towing velocity.

[5]Springston, G.B. Jr., "Generalized Hydrodynamic Loading Functions for Bare and Faired Cables in Two-Dimensional Steady-State Cable Configurations," NSRDC Report 2424 (Jun 1967).

$$-T\frac{d\phi}{ds_o} + I + \sin\phi\, W = 0 \qquad (1)$$

$$\frac{dT}{ds_o} + G + \cos\phi\, W = 0 \qquad (2)$$

$$\frac{ds}{ds_o} = 1 + \epsilon \qquad (3)$$

$$\frac{dx}{ds_o} = (1 + \epsilon)\sin\phi \qquad (4)$$

$$\frac{dy}{ds_o} = (1 + \epsilon)\cos\phi \qquad (5)$$

where T = cable tension

ϕ = angle of the cable segment with the vertical (see Figure 1)

s_o = reference cable length (when $T = T_o$) measured from the initial point

T_o = reference tension

I, G = normal and tangential drag forces, respectively, per unit length acting on the cable

W = weight in fluid per unit length of the cable

s = stretched cable length measured from the initial point

ϵ = cable strain; $\epsilon = 0$ at $T = T_o$

x = horizontal displacement, positive to the right

y = vertical displacement, positive downward

For smooth, approximately round cables, the normal and tangential drags may be taken as respectively proportional to the squares of the velocities normal and tangential to the cable[5]

$$I = \frac{1}{2}\rho C_D d c_n |c_n| \qquad (6)$$

$$G = \frac{1}{2}\rho C_T d c_t |c_t| \qquad (7)$$

where ρ = fluid density

C_D, C_T = normal and tangential drag coefficients respectively

d = cable diameter

c_n = component of the current normal to the cable = $c\cos\phi$

c_t = component of the current tangential to the cable = $-c\sin\phi$

c = magnitude of the current, taken to act only in the x-direction

The tension-strain function is assumed to be of the form[6]

$$T - T_o = C_1 \epsilon^{C_2} \tag{8}$$

where C_1 = constant of elasticity; C_1 = AE for a linearly elastic cable

A = cross-sectional area = $\pi d^2/4$ for a round cable

E = modulus of elasticity

C_2 = an exponent; C_2 = 1 for a linearly elastic cable

Equation (8) enables a nonlinear tension-strain relation to be modeled by only two input variables, C_1 and C_2. It is more convenient to express ϵ as a function of $(T - T_o)$ in order to eliminate it in Equations (3) through (5):

$$\epsilon = \left(\frac{T - T_o}{C_1}\right)^{1/C_2} \tag{9}$$

INTERMEDIATE BODIES

It is assumed that conditions at the top of the cable are known and the integration of Equations (1) through (5) proceeds down the cable. At an intermediate body, the integration must be interrupted and the unknown cable variables T_u and ϕ_u below the body must be related to the known variables T_k and ϕ_k above the body. Reducing the three-dimensional equations contained in References 7 and 8 to the present two-dimensional case results in the following two equations for T_u and ϕ_u:

$$T_u = \sqrt{(\sin \phi_k \; T_k + D_x)^2 + (-\cos \phi_k \; T_k + W_B)^2} \tag{10}$$

$$\phi_u = \tan^{-1} \frac{\sin \phi_k \; T_k + D_x}{\cos \phi_k \; T_k + W_B} \tag{11}$$

where D_x is the drag on the body and

[6] Thresher, R.W. and J.H. Nath, "Anchor-Last Deployment Procedure for Mooring," Oregon State University Report 73-5 (Jun 1973).

[7] Wang, H.T., "Effect of Nonplanar Current Profiles on the Configuration of Moored Cable Systems," NSRDC Report 3692 (Oct 1971).

[8] Wang, H.T., "A FORTRAN IV Program for the Three-Dimensional Steady-State Configuration of Extensible Flexible Cable Systems," NSRDC Report 4384 (Sep 1974).

$$D_x = \frac{1}{2} \rho C_D A_x c |c| \qquad (12)$$

Here also, $C_D A_x$ is the drag area of the body for flow in the x-direction and W_B is the weight of the body in fluid.

BOUNDARY CONDITIONS

Initial Value Cases

The integration of the above differential equations is most convenient when the tension T and the angle ϕ are known at one end of the cable. These are known for certain cases of single-point moored cables and towing cables. For the moored cases, the program starts with the known conditions at the top of the cable and integrates the five differential equations until the lower end of the cable is reached. This is the simplest case for the program since the numbering of the cable segments and intermediate bodies starts at the top of the cable. For towing cable cases, where the conditions are known at the lower towed body, the program integrates the differential equations twice. They are first integrated from the towed body to the upper point, thus fixing the conditions at this point. Then, in order to conform to the numbering system which is used for the dynamic calculations, the equations are integrated once again from the upper point down to the lower towed body.

Boundary Value Cases

In many applications the values of T and ϕ are not known *a priori* at any point along the cable. It is necessary to treat these cases as boundary value problems and use iteration techniques to obtain the solution. The present program contains the iteration schemes for two cases of particular interest for oceanobuoy systems: a cable of given length moored in a given ocean depth[9] and a free-floating cable system.[10] The iteration subroutine is written so that the user may conveniently implement iteration schemes for other applications.

[9] Wang, H.T. and B.L. Webster, "Current Profiles Which Give Rise to Nonunique Solutions of Moored Cable Systems," Paper OTC 1538, Fourth Annual Offshore Technology Conference, Houston, Texas (May 1972).

[10] Wang, H.T. and T.L. Moran, "Analysis of the Two-Dimensional Steady-State Behavior of Extensible Free-Floating Cable Systems," NSRDC Report 3721 (Oct 1971).

OCEAN SURFACE WAVES

DESCRIPTION OF MOTION

For ocean depths greater than one-half the wavelength,[11] the water particle trajectories due to a single progressive wave are, according to linearized first-order theory, given by[11,12]

$$x_w = a_w e^{-ky} \cos(kx - \sigma t + \theta_w) \tag{13a}$$

$$y_w = -a_w e^{-ky} \sin(kx - \sigma t + \theta_w) \tag{13b}$$

where x_w, y_w = water particle displacements in the (x, y) directions, respectively

a_w = wave amplitude

k = wave number = $2\pi/\lambda$

λ = wavelength

σ = circular frequency = $\sqrt{2\pi g/\lambda} = 2\pi f$

f = frequency

t = time

g = gravity constant = 32.2 ft/sec² (9.81 m sec⁻²)

θ_w = phase angle

It is of interest to note that the trajectories describe circular orbits with a radius which decays exponentially with depth.

For an irregular sea consisting of N distinct components, the resultant water particle displacements are obtained by a summation of the above expressions, resulting in

$$x_w = \sum_{i=1}^{N} a_{wi} e^{-k_i y} \cos(k_i x - \sigma_i t + \theta_{wi}) \tag{14a}$$

$$y_w = -\sum_{i=1}^{N} a_{wi} e^{-k_i y} \sin(k_i x - \sigma_i t + \theta_{wi}) \tag{14b}$$

Differentiations with respect to time yield the following results for water particle velocities and accelerations

[11] Lamb, H., "Hydrodynamics," Sixth Edition, Dover Publications, New York (1945), pp. 363-370, pp. 152-155.

[12] Wehausen, J.V. and E.V. Laitone, "Surface Waves," in "Handbuch der Physik," Vol 9, Springer Verlag, Berlin (1960), pp. 446-778.

$$\dot{x}_w = \sum_{i=1}^{N} \sigma_i a_{wi} e^{-k_i y} \sin (k_i x - \sigma_i t + \theta_{wi}) \tag{15a}$$

$$\dot{y}_w = \sum_{i=1}^{N} \sigma_i a_{wi} e^{-k_i y} \cos (k_i x - \sigma_i t + \theta_{wi}) \tag{15b}$$

$$\ddot{x}_w = \sum_{i=1}^{N} - \sigma_i^2 a_{wi} e^{-k_i y} \cos (k_i x - \sigma_i t + \theta_{wi}) \tag{16a}$$

$$\ddot{y}_w = \sum_{i=1}^{N} \sigma_i^2 a_{wi} e^{-k_i y} \sin (k_i x - \sigma_i t + \theta_{wi}) \tag{16b}$$

CHOICE OF COMPONENTS

The computer program allows the user two options for describing an irregular sea. He may specify the values of N, a_{wi}, σ_i, and θ_{wi} or he may use an energy spectrum $S_S(\sigma)$ to define the wave amplitudes

$$a_{wi} = \sqrt{S_S(\sigma_i)\,\Delta\sigma} \tag{17}$$

where $\sigma_i = \sigma_{i-1} + \Delta\sigma$

$\Delta\sigma = (\sigma_u - \sigma_\ell)/N$

σ_u = upper limit of the significant range of σ's

σ_ℓ = lower limit of the significant range of σ's

The program uses the Pierson-Moskowitz energy sea spectrum of the form

$$S_S(\sigma) = \frac{A}{\sigma^5} e^{-B/\sigma^4} \tag{18}$$

where A = 0.0081 g^2 and B = 33.56 $h_{1/3}^2$. Here $h_{1/3}$ is the significant wave height, the average of the one-third highest peak-to-trough heights. As reported by Frank and Salvesen,[13] the 11th International Towing Tank Conference (Tokyo) (1966) recommended the spectrum in this form for computations when information is not available on typical sea spectra.

[13]Frank, W. and N. Salvesen, "The Frank Close-Fit Ship-Motion Computer Program," NSRDC Report 3289 (Jun 1970).

Other forms for $S_S(\sigma)$ can, of course, be conveniently programmed. Values for $h_{1/3}$, σ_u, and σ_ℓ for State 0 to 9 seas may be found in Table 1 of Reference 13. The program sets the values of θ_{wi} to be evenly spaced from θ_{wi} to $360-\theta_{wi}$ degrees.

PRESCRIBED SURFACE MOTIONS

The program allows the user either to prescribe the motion at the surface or to describe it by means of differential equations of motion for a surface buoy

If the surface buoy or ship is sufficiently large that its motions are not appreciably affected by the presence of the cable, these motions may be calculated separately and used as input for the present program. Several programs are available to calculate the pitch and heave motion responses of surface ships, for example, the Frank Close-Fit Ship Motion Computer Program.[13] This approach is also valid for laboratory simulations of cable dynamics where the motions at the upper end of the cable are often prescribed. A third area of application could be a full-scale trial where the motions of the surface ship or platform can be readily measured.

The program considers the prescribed motion of the end of the cable as composed of a series of sinusoidal components in the horizontal and vertical directions

$$x_s = \sum_{i=1}^{N} a_{xi} \cos(-2\pi f_i t + \theta_{si}) \tag{19}$$

$$y_s = \sum_{i=1}^{N} -a_{yi} \sin(-2\pi f_i t + \theta_{si}) \tag{20}$$

where x_s, y_s = horizontal and vertical components of the surface motion, respectively

a_{xi}, a_{yi} = amplitudes for the ith component of x_s and y_s, respectively

f_i, θ_{si} = frequency and phase angle for the ith component, respectively

If so desired, other forms for the prescribed motion may be conveniently added to the program, e.g., other functions of time such as powers of t or exponentials

SURFACE BUOY EQUATIONS

GENERAL CONSIDERATIONS

It is well known that the added mass and damping coefficients of surface buoys are, in general, functions of the frequency of the oscillation.[14,15] In the time domain, this requires the solution of integrodifferential equations which contain convolution integrals. Alternatively, if the frequency-dependent coefficients can be expressed as simple polynomials of the frequency, the integrodifferential equations may be replaced by a set of higher order differential equations.[14] In either case, the solutions are complex and/or time-consuming in the time domain. Thus, surface buoy motions have usually been solved in the frequency domain. In this approach, the steady-state harmonic response is obtained for each frequency component of the exciting surface waves. The total response to the sum of the individual wave components is then obtained by linear superposition. Experiments have shown that this procedure generally yields satisfactory results for pitch and heave motions of surface ships.

Because of difficulties in solving buoy equations in the time domain, the frequency domain approach has also been used to study the motion of cable-buoy systems. Perhaps the most comprehensive of these studies is the Goodman et al. computer program[16] which considers four different buoy shapes. In addition to facilitating the solution for general buoy shapes, the frequency domain approach has the additional advantages of immediately giving the steady-state harmonic response (no need to wait for the transient response to die down) and of reducing the computer time required to obtain cable motions.[17] However, the drawbacks to this approach include neglect of all nonlinearities and the assumption that all the dynamic response variables are small compared to their steady-state values. This approach would not be able to predict, for example, the large dynamic snap loads which occur when the cable goes slack.

In view of the above drawbacks and also in view of the existence of the comprehensive frequency-domain computer program described in Goodman et al.,[16] it was decided to use a

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[14]Tick, L.J., "Differential Equations with Frequency-Dependent Coefficients," Journal of Ship Research, Vol. 3, No. 2, pp. 45-46 (Oct 1959).

[15]Ogilvie, T.F., "Recent Progress toward the Understanding and Prediction of Ship Motions," Fifth Symposium of Naval Hydrodynamics, Bergen, Norway, pp. 3-128 (Sep 1964).

[16]Goodman, T.R. et al., "Static and Dynamic Analysis of a Moored Buoy System," National Data Buoy Center Report 6113.1 (Apr 1972).

[17]Wang, H.T., "A Two-Degree-of-Freedom Model for the Two-Dimensional Dynamic Motions of Suspended Extensible Cable Systems," NSRDC Report 3663 (Oct 1971).

time domain approach in the present study. In order to make this approach feasible, it was important to find classes of buoys which did not have frequency-dependent added mass and damping coefficients. A literature search revealed two such classes: spar buoys[18,19] and small buoys. Spar buoys are buoys with circular cross sections and large draft-to-diameter ratios H/b. Because of their slenderness, the added inertia terms of these buoys are essentially those for infinite fluid, and the frequency-dependent wave damping coefficients are zero to first order approximation.[18] The other class corresponds to buoys whose typical dimension a is so small compared to the ocean wavelengths λ that the reduced frequency $\bar{\sigma}$ given by

$$\bar{\sigma} = 2\pi \frac{a}{\lambda} \ll 1 \tag{21}$$

is much less than unity for the range of λ values corresponding to ocean waves of interest.

For surface buoys of sonobuoy systems, whose typical dimension is of the order of 1 ft (0.305 m), the above condition holds for the large majority of sea states. When Equation (21) holds, the wave damping terms go to zero and the added inertia terms for $\bar{\sigma} = 0$ may be used. In this case, the ocean surface behaves essentially as a rigid plane,[20] and for the case of a buoy whose axis of symmetry is aligned with the y-axis, the added mass in surge is equal to the infinite fluid value. The added mass coefficients for pitch and heave must be calculated separately for each shape considered. Since these coefficients have been studied for several cases of oblate and prolate spheroids,[21-24] and also because they represent mathematical shapes which are similar to surface buoys of sonobuoy systems, it was decided to represent the small buoys by prolate and oblate spheroids. Both types of spheroids are characterized by having two of their three axes equal in length. The limiting cases for a prolate spheroid are a

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[18] Newman, J.N., "The Motions of a Spar Buoy in Regular Waves," David Taylor Model Basin Report 1499 (May 1963).

[19] Rudnick, P., "Motion of A Large Spar Buoy in Sea Waves," Journal of Ship Research, Vol. 11, No. 4, pp. 257-267 (Dec 1967).

[20] Newman, J.N., "Marine Hydrodynamics (Lecture Notes)," M.I.T. Dept Nav. Arch. and Mar. Eng. (Spring Term 1971).

[21] Havelock, T., "Waves due to a Floating Sphere Making Periodic Heaving Oscillations," Preceedings of the Royal Society, Vol. 231, Series A, pp. 1-7 (Jul 1955).

[22] MacCamy, R.C., "On the Heaving Motion of Cylinders of Shallow Draft," Journal of Ship Research, Vol. 7, No. 3, pp. 34-43 (Dec 1961).

[23] Kim, W.D., "On the Forced Oscillations of Shallow-Draft Ships," Journal of Ship Research, Vol. 7, No. 2, pp. 7-18 (Oct 1963).

[24] Kim, W.D., "On a Free-Floating Ship in Waves," Journal of Ship Research, Vol. 10, No. 3, pp. 182-191 (Sep 1966).

long thin cylinder and a sphere, and the limiting cases for an oblate spheroid are a thin circular disk and again a sphere. It can be seen from these limiting cases, that prolate and oblate spheroids can be used to generate a wide range of shapes.

DIFFERENTIAL EQUATIONS OF MOTION

The linearized differential equations for the surge, heave, and pitch motions of a surface buoy or ship freely floating in an inviscid fluid are well known; see, for example, Frank and Salvesen[13] and Newman.[18] These equations usually contain the inertia forces (including the added hydrodynamic inertia forces), the wave-damping forces, the exciting forces due to the incoming ocean waves, and the restoring forces due to buoyancy. The resulting equations are usually solved in the frequency domain. As mentioned previously, the wave-damping forces may be neglected, to first order, for the two types of buoys considered in the present report. The forces due to viscous drag and cable tension, which are not usually considered in the above studies, are included in the present formulation. The viscous drag forces which are quadratic in the motion velocities of the float, are usually omitted since they make the equations nonlinear and complicate solutions in the frequency domain. The inclusion of these forces poses no problem in a time-domain analysis. The cable forces are, of course, zero for a freely floating buoy.

If the above forces acting on the buoy (shown in Figure 2) are considered and the pitch angle ψ is taken to be small such that

$$\sin \psi \approx \psi \tag{22a}$$

$$\cos \psi \approx 1, \tag{22b}$$

the three differential equations for the surge ξ, heave ζ, and pitch ψ are as follows

$$\left[A_{\xi\xi} = (m + K_S \rho V)\right] \ddot{\xi} + \left[A_{\xi\psi} = -\rho \int_0^H (y - y_G)\, k_S(y)\, S(y)\, dy\right] \ddot{\psi} = FK_x + D_x + T_x + T_{1wx} \tag{23}$$

$$\left[A_{\eta\eta} = (m + K_H \rho V)\right] \ddot{\zeta} = -\rho g S_w (\zeta - y_w) + FK_y + D_y + T_y - T_{ys} \tag{24}$$

$$A_{\xi\psi}\, \ddot{\xi} + \left\{A_{\psi\psi} = \left[I + \rho \int_0^H (y - y_G)^2\, k_S(y)\, S(y)\, dy\right]\right\} \ddot{\psi} = \rho g V\, \overline{BG}\, \psi + FK_\psi$$

$$- \overline{BG}\, D_x + (-r_y\, \psi + r_x)\, T_y - (r_x\, \psi + r_y)\, T_x - r_{wy}\, T_{1wx} \tag{25}$$

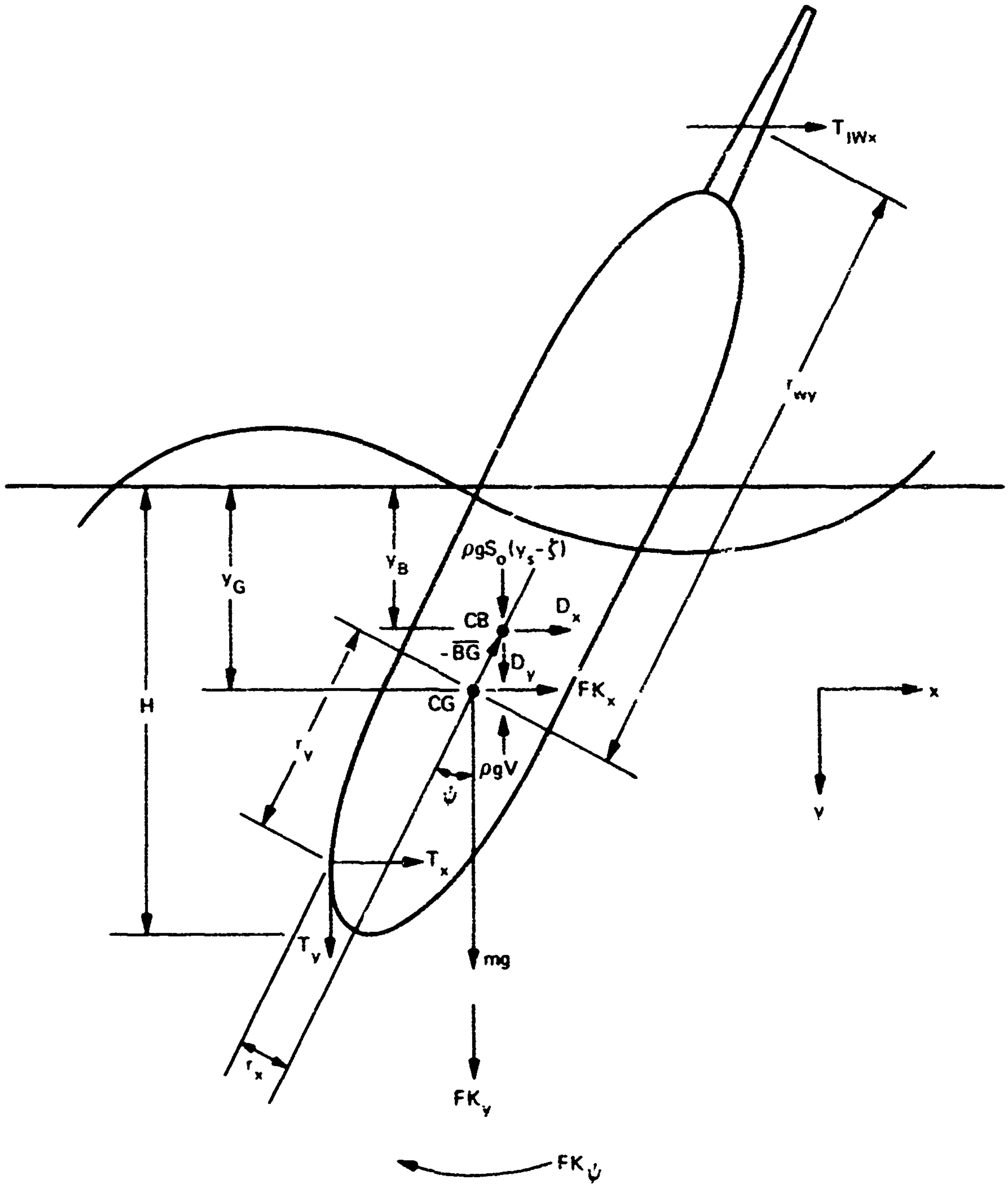

Figure 2 – Definition of Forces Acting on Surface Buoy

where	$A_{\xi\xi}$, $A_{\xi\psi}$, $A_{\eta\eta}$, and $A_{\psi\psi}$	= inertia coefficients defined above
	m	= mass of the buoy
	K_S and K_H	= added mass coefficients for surge and heave, respectively
	V	= submerged volume
	H	= draft
	y_G	= distance of the center of gravity below the undisturbed free surface
	$k_S(y)$	= local added mass coefficient for surge
	$S(y)$	= local cross-sectional area
	FK_x, FK_y	= exciting forces due to surface waves in the x- and y-directions, respectively
	FK_ψ	= exciting moment about the center of gravity due to surface waves
	D_x, D_y	= viscous drag forces in the x- and y-directions, respectively
	T_x, T_y	= components of the cable tension in the x- and y-directions, respectively, at the attachment point to the buoy
	T_{1wx}	= wind loading on the buoy in the x-direction
	T_{ys}	= steady-state component of tension in the y-direction at the attachment point to the buoy
	S_w	= waterplane area of the buoy
	y_w	= vertical displacement of the ocean surface, defined in Equation (14b)
	I	= moment of inertia about the center of gravity
	$-\overline{BG}$	= $y_B - y_G$
	y_B	= distance of the center of buoyancy below the undisturbed free surface
	r_x, r_y	= horizontal and vertical distances measured from the center of gravity to the cable attachment point
	r_{wy}	= vertical distance measured from the center of gravity to the center of the wind loading force

In Equations (23)–(25), a dot denotes differentiation with respect to time.

The added inertia coefficients, presented below, are all calculated for the case $\psi \equiv 0$. It should be noted that the moment terms on the right-hand side of Equation (25) may be readily changed to account for large values of ψ which negate approximations (22a) and (22b). However, the added inertia terms on the left-hand side of Equations (23) through (25) must be calculated (by potential flow methods) for each new value of ψ. For example, for a large value of ψ, the added mass in surge for a small spheroidal buoy is no longer equal to the infinite fluid value since in this case, there will be motion of the fluid perpendicular to the free surface.

Under static conditions, the submerged volume V must support both the weight of the buoy in air (mg) and the vertical component of the steady-state tension (T_{ys})

$$\rho g V = mg + T_{ys} \tag{26a}$$

$$V = \frac{m}{\rho} + \frac{T_{ys}}{\rho g} \tag{26b}$$

If the input dimensions for the draft and cross-sectional areas of the buoy are such that the submerged volume does not equal the value given in Equation (26b), the program internally multiplies the cross-sectional areas by a constant factor so that the submerged volume becomes exactly equal to the value given by this equation. All of the added inertia and wave-exciting forces given in the following sections are based on this volume.

The following two sections present derivations for the added inertia coefficients K_S, K_H, k_S and the wave-exciting forces FK_x, FK_y, FK_ψ for the two classes of buoys considered: spar buoys and small spheroidal buoys.

SPAR BUOYS

Because of the slenderness of the spar buoy, Newman[18] shows that its added inertias for surge and pitch are identical to those in infinite fluid. Since the spar buoy has a circular cross section, the surge inertia coefficients k_S and K_S are both equal to 1, leading to the following definitions for the added surge and pitch inertia terms in Equations (23) through (25):

$$K_S = k_S = 1 \tag{27a}$$

$$m + K_S \rho V = m + \rho V \tag{27b}$$

$$\rho \int_0^H (y - y_G)\, k_S(y)\, S(y)\, dy = \rho \int_0^H (y - y_G)\, S(y)\, dy \tag{27c}$$

$$\rho \int_0^H (y - y_G)^2\, k_S(y)\, S(y)\, dy = \rho \int_0^H (y - y_G)^2\, S(y)\, dy \tag{27d}$$

Newman takes the buoy to be sufficiently slender so that the added mass for heave may be neglected. Adee and Bai[25] have shown experimentally that for the case of a circular cylinder, it is more accurate to add a term corresponding to one-half the added mass of a circular disk (with the same diameter as that of the cylinder) heaving in infinite fluid.

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[25] Adee, B.H. and K.J. Bai, "Experimental Studies of the Behavior of Spar Type Stable Platforms in Waves," University of California (Berkeley) Report NA-70-4 (Jul 1970).

This correction term has been incorporated into the present formulation by taking the radius of the disk to be the mean radius of the spar buoy $\bar{r}$, defined by

$$\pi \bar{r}^2 H = V, \bar{r} = \sqrt{\frac{V}{\pi H}}$$

Since one-half of the added inertia of a circular disk heaving in infinite fluid[11] is $(4/3)\rho \bar{r}^3$, the following expression is obtained for K_H in Equation (24)

$$K_H = \frac{4}{3} \frac{1}{V} \bar{r}^3 = \frac{4}{3} \frac{1}{V} \left(\frac{V}{\pi H}\right)^{3/2} \tag{28}$$

Newman shows that the wave-exciting forces are simply the Froude-Krylcv forces, which may be obtained by integrating the pressure field generated by the ocean waves around the contour of the buoy. The following expressions are obtained for FK_x and FK_ψ

$$FK_x = -2 \sum_{i=1}^{N} \left[\sigma_i^2 a_{wi} \cos(k_i x - \sigma_i t + \theta_{wi}) Q_o(k_i)\right] \tag{29}$$

$$FK_\psi = 2 \sum_{i=1}^{N} \left[\sigma_i^2 a_{wi} \cos(k_i x - \sigma_i t + \theta_{wi}) Q_1(k_i)\right] \tag{30}$$

where

$$Q_o(k_i) = \rho \int_0^H e^{-k_i y} S(y)\, dy$$

$$Q_1(k_i) = \rho \int_0^H e^{-k_i y} (y - y_G) S(y)\, dy$$

For the heave motion, the Froude-Krylov force given by Newman has been modified to account for the additional heave added-mass term given in Equation (28). This modification has been so made that in the limiting case of a very small spar buoy (which would follow the motions of the waves in the absence of cable forces), the wave-exciting term in Equation (24) would be exactly equal to the inertia term on the left-hand side of the equation. The resulting force has the from

$$FK_y = \left[1 + \frac{4}{3} \rho \left(\frac{V}{\pi H}\right)^{3/2}\right] \sum_{i=1}^{N} \left[\sigma_i^2 a_{wi} \sin(k_i x - \sigma_i t + \theta_{wi}) Q_o(k_i)\right] \tag{31}$$

The expression given by Newman does not contain the correction term $(4/3)\rho(V/\pi H)^{3/2}$.

SMALL SPHEROIDAL BUOYS

As mentioned previously, for the limiting case of zero reduced frequency where the free surface behaves as a rigid plane, the coefficient for the surge added mass K_S is equal to the infinite fluid value. These coefficients may be calculated by the formulas and tables given in Lamb.[11]

The added inertia coefficients for heave, pitch, and coupled pitch-surge motions which have components normal to the free surface are not the same as the coefficients for infinite fluid. Instead, they must be calculated separately to incorporate the rigid free-surface condition. Inspection of Equations (23) and (25) shows that the added inertia terms for pitch and coupled pitch-surge motions may be defined as follows

$$\int_0^H (y - y_G)^2 \, k_S(y)\, S(y)\, dy = \int_0^H (y^2 - 2yy_G + y_G^2)\, k_S(y)\, S(y)\, dy$$

$$= \mu_{55}\, r_w^2\, V - 2y_G(-\mu_{15})\, r_w V + y_G^2 K_S V \tag{32a}$$

$$-\int_0^H (y - y_G)\, k_S(y)\, S(y)\, dy = \mu_{15}\, r_w V + y_G K_S V \tag{32b}$$

where r_w is the maximum radius of the buoy and is used to render the coefficients μ_{55} and μ_{15} dimensionless.

Thus, a calculation of μ_{55}, μ_{15}, and K_H, along with the values of K_S for infinite fluid as given in Lamb, completely determines all the added inertia terms in Equations (23) through (25). Bai[26] has used a finite element approach to calculate coefficients μ_{55}, μ_{15}, and K_H for spheroids with draft to maximum radius ratios (H/r_w) ranging from 0.1 to 10. His results agree well with previous results[21-24] for corresponding cases at the zero reduced frequency limit.

Principally for the sake of programming ease, the present program considers only the results for the case where the maximum radius lies at the free surface. Consideration of other radii at the free surface would introduce additional parameters to a description of the submerged buoy. In addition, it is expected that in most cases the maximum radius will be close to the free surface because most of the volume (and hence buoyancy capability) of the spheroid is concentrated in the region around the maximum radius. Results for several cases where the waterline does not occur at the maximum radius are presented in Bai.[26]

[26] Bai, K.J., "The Zero-Frequency Hydrodynamic Coefficients of Vertical Axisymmetric Bodies at a Free Surface," Journal of Hydronautics (Jan 1977).

In the range $0.1 \leqslant H/r_w \leqslant 10.$, the coefficients μ_{15}, μ_{55}, K_H, and K_S are obtained by linearly interpolating between the values shown in Table 1.

TABLE 1 – VALUES OF ADDED INERTIA COEFFICIENTS FOR SPHEROIDAL BUOYS AT ZERO REDUCED FREQUENCY

H/r_w	K_S	K_H	μ_{55}	μ_{15}
0.1	0.074	12.84	1.27	0.3
0.2	0.143	5.84	0.55	0.264
0.3	0.2[illegible]	3.672	0.312	0.237
0.5	0.31	2.005	0.117	0.177
0.7	0.397	1.323	0.0358	0.1[illegible]
0.9	0.469	0.96	0.0038	0.0039
1.0	0.50	0.836	0.	0.
1.5	0.622	0.484	0.0731	-0 191
2.	0.704	0.323	0.272	-0.391
3.	0.804	0.18	0.993	-0.788
5.	0.894	0.082	3.65	-1.565
7.	0.933	0.049	8.20	-2.38
10.	0.96	0.028	20.0	-3.75

The values of K_S are those given by Lamb,[11] and the values of μ_{15}, μ_{55}, and K_H are the values given by Bai,[26] subject to two modifications at $H/r_w = 10.0$. The values of μ_{15} and μ_{55} for $H/r_w = 10$, respectively 20.0 and −3.75, correspond to those obtained by simply using strip theory with $k_S(y) = 1$ for $0 \leqslant y \leqslant H$. The corresponding values of μ_{15} and μ_{55} obtained by Bai are respectively 17.84 and −3.53. These modifications were made principally for the sake of providing continuity with the approximation used in the range $H/r_w > 10.0$, where the buoy is treated essentially as a spar buoy. There are two reasons for the differences between the strip theory and theoretical finite element calculations.[26] First, the strip theory approach neglects the flow around the lower end of the buoy, where $k_S(y) < 1$. Second, the finite element representation, where only the nodes of the elements are on the surface of the buoy, effectively models a smaller buoy. Both of these effects serve to make the strip theory values higher than the corresponding finite element results.

Wave-Exciting Forces

The exciting forces FK_x and FK_y in Equations (23) and (24) were written in a form which assumes that the buoy follows the wave motion in the absence of cable forces and

coupling between pitch and surge motions. This is the case for buoys with dimensions which are small compared to the lengths of the exciting waves. The resulting equations take the form

$$FK_x = (1 + K_S)\rho V \ddot{x}_w = -(1 + K_S)\rho V \sum_{i=1}^{N} \left[\sigma_i^2 a_{wi} \cos(k_i x - \sigma_i t + \theta_{wi})\right] \tag{33}$$

$$FK_y = (1 + K_H)\rho V \ddot{y}_w = (1 + K_H)\rho V \sum_{i=1}^{N} \left[\sigma_i^2 a_{wi} \sin(k_i x - \sigma_i t + \theta_{wi})\right] \tag{34}$$

The term $e^{k_i y}$ which appears in Equations (16a) and (16b) for $\ddot{x}_w$ and $\ddot{y}_w$ has been omitted in the above equations since it is ≈ 1 under the assumption of small reduced frequency, Equation (21).

The pitch-exciting moment is computed by noting that because of the symmetry of the buoy about the vertical axis, only the horizontal wave motions make a contribution to pitch, resulting in

$$FK_\psi = -\rho \int_0^H (y - y_G)\ddot{x}_w \left[1 + k_S(y)\right] S(y)\, dy$$

$$= \rho(-\overline{BG}\, V + \mu_{15} r_w V + y_G K_S V)\ddot{x}_w$$

$$= -\rho V(-\overline{BG} + \mu_{15} r_w + y_G K_S) \sum_{i=1}^{N} \left[\sigma_i^2 a_{wi} \cos(k_i x - \sigma_i t + \theta_{wi})\right] \tag{35}$$

Again, under the assumption of small reduced frequency, the term $e^{-k_i y}$ has been set equal to 1 in the expression for $\ddot{x}_w$.

DYNAMIC CABLE EQUATIONS

GENERAL CONSIDERATIONS

As mentioned previously, equations for the present study are solved in the time domain. Previous cable studies have considered two major approaches in the time domain: the method of characteristics and the finite element method. The method of characteristics is an elegant method which reduces the original set of partial differential equations to a set of ordinary differential equations which are integrated along characteristic lines or wavefronts. This method furnishes valuable insight into the various modes of cable motion but solution times are typically very large.[2]

The finite element method seeks to represent the actual cable system by a series of segments and nodes. The original set of partial differential equations is then reduced to a set of ordinary differential equations of motion for the nodes. This method facilitates the modeling of nonuniform properties along the cable as well as the presence of intermediate bodies. The method is also quite flexible in that the number and location of nodes is left to the judgment of the user. In arriving at his selection of nodes, he may consider such factors as the type and accuracy of the dynamic information desired, the amount of computer time available, the complexity of the cable system, and the spatial variation of the environmental velocity profiles.

Principally for reasons of generality and flexibility, the finite element approach was used to model the cable. Straight elements are used in the present formulation. Webster[27] studied the use of higher order curved elements to model cable shape and concluded that the first order straight element appears to be the most cost-effective. In particular, he showed that one second-order quadratic element would have to be as accurate as at least eight straight elements before its use would be economical.

Before deciding on the final formulation, a number of preliminary approaches for obtaining the differential equations of motion for the nodes were explored. Two approaches in particular were considered in some detail.

PRELIMINARY APPROACHES

In one approach, the equations were formulated in a coordinate system aligned with the cable segment. This is the approach used by Rupe and Thresher[28] to obtain the dynamic motions of an inextensible, uniform cable. For the present case of an extensible cable, the two unknowns are the inclination and stretch of each segment. This is the most natural way of describing the configuration of a segment. In addition, certain cable forces such as tension, added inertia, and drag forces are most conveniently expressed in directions normal and tangential to a cable segment. However, in the presence of intermediate bodies along the cable, for which the inertia and drag are most conveniently expressed in the spatial x- and y-directions, the resulting equations are greatly complicated by the transformation required to express the body forces in the cable coordinate system. The cable system considered by Rupe and Thresher is free of intermediate bodies.

[27] Webster, R.L., "An Application of the Finite Element Method to the Determination of Nonlinear Static and Dynamic Responses of Underwater Cable Structures," General Electric Report R76EMH2 (Jan 1976).

[28] Rupe, R.C and Thresher, R.W., "The Anchor-Last Deployment Problem for Inextensible Mooring Lines," ASME Paper 74-WA/OcT-5 (Dec 1974).

Wang[29] has shown that relatively few segments are required to accurately describe the overall steady-state configuration of a cable; these results suggested a second novel approach. The cable was conventionally divided into a number of straight segments and two differential equations in the x- and y-directions were written for the nodes at the ends of the segments. However, each straight segment was subdivided into a number of intermediate nodes, as shown in Figure 3.

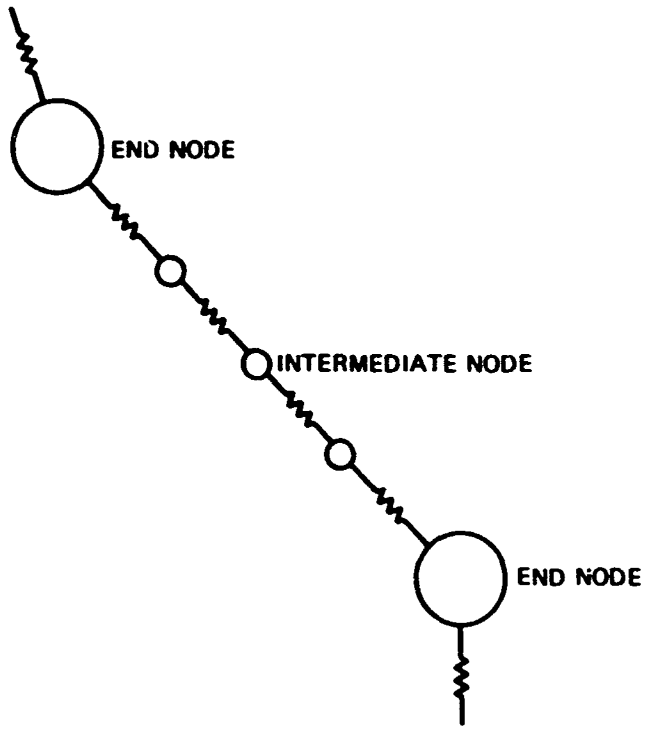


Figure 3 – Finite Element with Intermediate Nodes

Since these intermediate nodes were forced to move along the straight cable segment, only one differential equation was needed to describe their longitudinal motion. The principal intention of this approach was to have the end nodes describe the overall cable configuration and the intermediate nodes describe the variation of tension along a cable segment. There was not sufficient time in the present study to fully explore this approach. However, it was found that a certain amount of bookkeeping was required in the program to differentiate between the "end" and "intermediate" nodes. Also, although this approach reduces the total number of differential equations from that required by more conventional approaches, the

[29] Wang, H.T., "Determination of the Accuracy of Segmented Representations of Cable Shape," Journal of Engineering for Industry, Vol. 97, No. 2, Series B, pp. 472-478 (May 1975).

integration time step still depends on the distance between intermediate nodes and the elastic modulus of the cable. For short distances and nearly inextensible cables, the size of the integration steps becomes very small, which increases computer time.

FINAL FORMULATION

In view of the above, selection of the final finite element model was as shown in Figure 4. The continuous cable is divided into a number of massless straight elastic segments. The inertia, weight, and drag forces acting on each cable segment are equally divided between the two nodes at the ends of the segment.

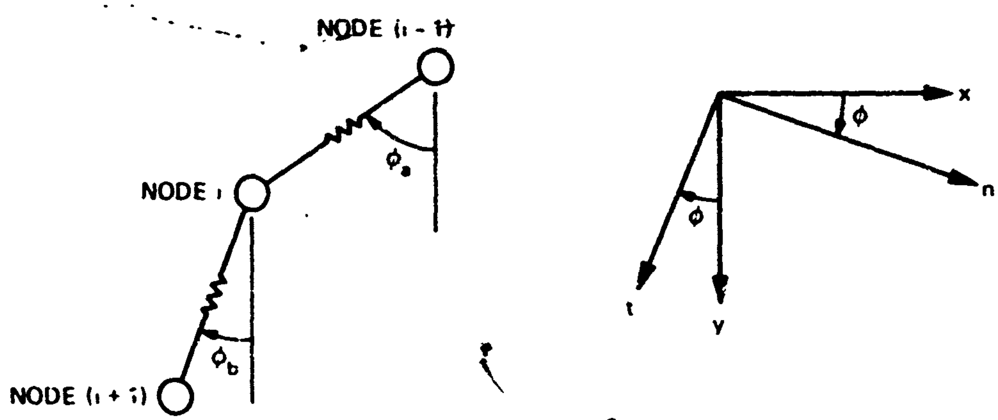


Figure 4 – Final Finite Element Model

Two second-order differential equations of motion are written in the spatial x- and y-directions for each node i, as follows

$$J_{x_i}\ddot{x}_i + K_i\ddot{y}_i = F_{x_i} = T_{x_i} + D_{nx_i} + D_{tx_i} + D_{Bx_i} \tag{36}$$

$$K_i\ddot{x}_i + J_{y_i}\ddot{y}_i = F_{y_i} = T_{y_i} + D_{ny_i} + D_{ty_i} + D_{By_i} + W_{C_i} + W_{B_i} \tag{37}$$

$$i = 1, 2, \ldots, M$$

where J_x, J_y, K = inertia coefficients defined below in Equation (43)

x, y = subscripts denoting the x- and y-directions, respectively

F = sum of the tension, drag, and gravity forces acting on the node

T = tension in the cable due to stretch and internal damping

D_n = normal drag force acting on the cable

D_t = tangential drag force acting on the cable

D_B = drag force acting on the intermediate body

W_C = weight of the cable in fluid

W_B = weight of the intermediate body in fluid

M = total number of nodes

Detailed definitions of the cable forces are now given, and the drag and inertia forces for the intermediate bodies are defined in the next major section.

It is most convenient to solve the set of 2M differential equations (36) and (37) with $\ddot{x}_i$ and $\ddot{y}_i$ uncoupled, as follows

$$\ddot{x}_i = (J_{y_i} F_{x_i} - K_i F_{y_i})/(J_{x_i} J_{y_i} - K_i^2) \tag{38a}$$

$$\ddot{y}_i = (J_{x_i} F_{y_i} - K_i F_{x_i})/(J_{x_i} J_{y_i} - K_i^2) \tag{38b}$$

DEFINITION OF CABLE FORCES

Inertia Forces

Each cable segment is taken to be a long thin cylinder for which fluid inertia is added only for acceleration normal to the segment. Thus, in a coordinate system aligned with the segment, the inertia force $\vec{F}_{IC}$ for the cable segment is simply given by

$$\vec{F}_{IC} = (\mu \ell_o + \alpha \rho A \ell_o)\vec{a}_n + \mu \ell_o \vec{a}_t \tag{39}$$

where μ = mass per unit length of the cable

ℓ_o = reference length of the cable segment

α = added mass coefficient = 1.0 for a round cable

A = cross-sectional area of the cable

$\vec{a}_n, \vec{a}_t$ = accelerations respectively normal and tangential to the cable segment

In this equation, an arrow denotes a vector.

In the fixed x- and y-directions, for which the differential equations are written, the inertia coefficients are not constants but rather are functions of cable inclination ϕ. For the coordinate systems shown in Figure 4, a_n and a_t are related to $\ddot{x}$ and $\ddot{y}$, respectively the accelerations in the x- and y-directions, by

$$a_n = \ddot{x} \cos \phi - \ddot{y} \sin \phi \tag{40a}$$

$$a_t = -\ddot{x} \sin \phi + \ddot{y} \cos \phi \tag{40b}$$

The x- and y-components of a_n and a_t are, in turn, given by

$$a_{nx} = a_n \cos\phi = \ddot{x}\cos^2\phi + \ddot{y}\sin\phi\cos\phi \tag{41a}$$

$$a_{ny} = a_n \sin\phi = \ddot{x}\sin\phi\cos\phi + \ddot{y}\sin^2\phi \tag{41b}$$

$$a_{tx} = -a_t \sin\phi = \ddot{x}\sin^2\phi - \ddot{y}\sin\phi\cos\phi \tag{41c}$$

$$a_{ty} = a_t \cos\phi = -\ddot{x}\sin\phi\cos\phi + \ddot{y}\cos^2\phi \tag{41d}$$

The inertia force for the cable segment in the spatial coordinates x and y takes the form

$$\begin{aligned} \vec{F}_{IC} &= [(\mu\ell_o + \alpha\rho A\ell_o)\, a_{nx} + \mu\ell_o a_{tx}]\, \vec{i} \\ &\quad + [(\mu\ell_o + \alpha\rho A\ell_o)\, a_{ny} + \mu\ell_o a_{ty}]\, \vec{j} \end{aligned} \tag{42}$$

where $\vec{i}$, $\vec{j}$ are unit vectors in the x- and y-directions, respectively.

If one-half of the inertia force of the cable segments above and below the node are summed and the possible presence of an intermediate body at the node is taken into account, Equations (39) to (42) yield the following equation for the total inertia force $\vec{F}_I$ at the node

$$\begin{aligned} \vec{F}_I &= \left[\left(\frac{\mu_a \ell_{oa} + \mu_b \ell_{ob}}{2} + \frac{\alpha\rho A_a \ell_{oa}}{2}\cos^2\phi_a + \frac{\alpha_b \rho A_b \ell_{ob}}{2}\cos^2\phi_b + M_{BVx}\right)\ddot{x}\right. \\ &\quad \left. + \left(\frac{-\alpha\rho A_a \ell_{oa}}{2}\sin\phi_a\cos\phi_a - \frac{\alpha\rho A_b \ell_{ob}}{2}\sin\phi_b\cos\phi_b\right)\ddot{y}\right]\vec{i} \\ &\quad + \left[\left(\frac{-\alpha\rho A_a \ell_{oa}}{2}\sin\phi_a\cos\phi_a - \frac{\alpha\rho A_b \ell_{ob}}{2}\sin\phi_b\cos\phi_b\right)\ddot{x}\right. \\ &\quad \left. + \left(\frac{\mu_a \ell_{oa} + \mu_b \ell_{ob}}{2} + \alpha\rho A_a \ell_{oa}\sin^2\phi_a + \alpha\rho A_b \ell_{ob}\sin^2\phi_b + M_{BVy}\right)\ddot{y}\right]\vec{j} \\ &= (J_x\ddot{x} + K\ddot{y})\,\vec{i} + (K\ddot{x} + J_y\ddot{y})\,\vec{j} \end{aligned} \tag{43}$$

where subscripts a and b respectively denote the cable segments above and below the node and M_{BVx} and M_{BVy} are respectively the virtual mass, the mass plus the added mass, of the intermediate body for motions in the x- and y-directions.

Tension Force

For an extensible cable segment, the tension force T depends on the strain ϵ and the strain rate $\dot{\epsilon}$

$$T = T(\epsilon, \dot{\epsilon}) \tag{44}$$

where

$$\epsilon = \frac{\Delta \ell}{\ell_o} = \frac{\ell}{\ell_o} - 1 = \frac{\sqrt{(x_\ell - x_u)^2 + (y_\ell - y_u)^2}}{\ell_o} - 1 \tag{45}$$

$$\dot{\epsilon} = \frac{d\epsilon}{dt} = \frac{(\dot{x}_\ell - \dot{x}_u)(x_\ell - x_u) + (\dot{y}_\ell - \dot{y}_u)(y_\ell - y_u)}{\ell \ell_o} \tag{46}$$

Here ℓ is the stretched length of the cable segment and the subscripts ℓ and u respectively refer to the lower and upper ends of the cable segment.

Several relationships have been proposed in the literature for the form of this dependence. In the present study, the following relatively simple yet general relationship is used

$$T = T_o + C_1 \epsilon^{C_2} + C_I \dot{\epsilon} \tag{47}$$

where C_I is the internal damping coefficient. Note that the above dynamic tension differs from the static tension, Equation (8), by the addition of the linear internal structural damping term $C_I \dot{\epsilon}$. This model, commonly referred to as the Voigt model, has been used in previous cable studies, for example, by Huffman[30] and by Goeller and Laura.[31] Goeller and Laura show experimentally that this model adequately describes internal damping for nylon ropes except for frequencies significantly higher than the resonance frequency of the cable. Other more complex forms for the internal structural damping, such as those proposed by Reid,[32] can be conveniently incorporated into the program.

Since the cable segments above and below the node act on it, the following two expressions are obtained for T_x and T_y (respectively the x- and y-components of the resultant forces due to cable tension).

$$T_x = T_{ax} + T_{bx} = T_a \sin \phi_a - T_b \sin \phi_b \tag{48a}$$

$$T_y = T_{ay} + T_{by} = -T_a \cos \phi_a + T_b \cos \phi_b \tag{48b}$$

[30] Huffman, R.R., "The Dynamical Behavior of Extensible Cable in a Uniform Flow Field (An Investigation of the Towed Vehicle Problem)," Ph.D. Thesis, Purdue University (Jan 1969).

[31] Goeller, J.E. and P.A. Laura, "Analytical and Experimental Study of the Dynamic Response of Cable Systems," The Catholic University of America, Department of Mechanical Engineering, Themis Program 893, Report 70-3 (Apr 1970).

[32] Reid, R.O., "Dynamics of Deep-Sea Mooring Lines," Texas A&M University, Department of Oceanography, A&M Project 204, Reference 68-11F (Jul 1968).

Drag Forces

As shown previously in Equations (6) and (7), the static normal and tangential cable drags are taken to be respectively proportional to the squares of the normal and tangential components of the current velocity $\vec{c}$. In the dynamic case, the fluid velocity relative to the cable must include the ocean wave particle velocities $\dot{x}_w$ and $\dot{y}_w$ as well as the velocities $\dot{x}$ and $\dot{y}$ of the cable. The resultant expressions v_{rn} and v_{rt} for the relative velocities normal and tangential to the cable then take the form

$$v_{rn} = (c + \dot{x}_w - \dot{x}) \cos \phi + (\dot{y}_w - \dot{y}) \sin \phi = \dot{x}_r \cos \phi + \dot{y}_r \sin \phi \tag{49a}$$

$$v_{rt} = -(c + \dot{x}_w - \dot{x}) \sin \phi + (\dot{y}_w - \dot{y}) \cos \phi = -\dot{x}_r \sin \phi + \dot{y}_r \cos \phi \tag{49b}$$

where $\dot{x}_r = c + \dot{x}_w - \dot{x}$ and $\dot{y}_r = \dot{y}_w - \dot{y}$.

If one-half of the drag forces acting on the cable segments above and below the node are summed, the following equations are obtained for the resultant forces D_{nx}, D_{ny}, D_{tx}, and D_{ty} acting on the node

$$D_{nx} = \frac{1}{2} D_{na} \cos \phi_a + \frac{1}{2} D_{nb} \cos \phi_b \tag{50a}$$

$$D_{ny} = \frac{1}{2} D_{na} \sin \phi_a + \frac{1}{2} D_{nb} \sin \phi_b \tag{50b}$$

$$D_{tx} = -\frac{1}{2} D_{ta} \sin \phi_a - \frac{1}{2} D_{tb} \sin \phi_b \tag{50c}$$

$$D_{ty} = \frac{1}{2} D_{ta} \cos \phi_a + \frac{1}{2} D_{tb} \cos \phi_b \tag{50d}$$

where

$$D_{n(a,b)} = \frac{1}{2} \rho C_{D(a,b)} d_{(a,b)} \ell_{o(a,b)} v_{rn(a,b)} |v_{rn(a,b)}|$$

$$D_{t(a,b)} = \frac{1}{2} \rho C_{T(a,b)} d_{(a,b)} \ell_{o(a,b)} v_{rt(a,b)} |v_{rt(a,b)}|$$

$$v_{rn(a,b)} = \dot{x}_r \cos \phi_{(a,b)} + \dot{y}_r \sin \phi_{(a,b)}$$

$$v_{rt(a,b)} = -\dot{x}_r \sin \phi_{(a,b)} + \dot{y}_r \cos \phi_{(a,b)}$$

INTERMEDIATE BODIES

The magnitude and direction of the added inertia and drag forces for an arbitrary body depend, in general, in a complex manner on body shape and orientation relative to the flow. The modeling of intermediate bodies in previous cable studies has ranged from the very simple to the very complex. At one extreme, the presence of intermediate bodies has been neglected altogether, leading to a cable-only system. At the other extreme, some studies have paid very careful attention to a particular body, often the lower body of the system, and approximated the rest of the cable system in a simple manner.

After careful review of previous studies, formulations were selected for the present study which although relatively simple, can model most bodies of interest for sonobuoy systems. They are also applicable to other cable systems where the bodies are relatively small and/or conform to the shape limitations given below.

CONSTANT COEFFICIENTS

Inertia Forces

The inertia forces in the x- and y-directions are expressed as the virtual mass times the acceleration in these directions, where the virtual mass is the sum of the mass of the body M_B and the constant infinite fluid added mass. Thus, the virtual masses M_{BVx} and M_{BVy} which appear in Equation (43) are given by

$$M_{BVx} = M_B + K_x \rho V_B \tag{51a}$$

$$M_{BVy} = M_B + K_y \rho V_B \tag{51b}$$

where K_x, K_y are respectively the added mass coefficients for motions in the x- and y-directions and V_B is the reference volume, usually the volume of the body.

Drag Forces

Two formulations are used to describe the drag forces. In one, the drag components D_{Bx} and D_{By} are taken to have the form

$$D_{Bx} = \frac{1}{2} \rho C_{DAx} v_r \dot{x}_r \tag{52a}$$

$$D_{By} = \frac{1}{2} \rho C_{DAy} v_r \dot{y}_r \tag{52b}$$

where C_{DAx}, C_{DAy} are respectively the drag areas in the x- and y-directions and $v_r = \sqrt{\dot{x}_r^2 + \dot{y}_r^2}$ is the resultant fluid velocity relative to the body. This approach has been used by Walton and Polachek[33] and is exact for the case of a sphere. In this case, where $C_{DAx} = C_{DAy} = C_{DA}$, the resultant drag D_B is parallel to the resultant fluid velocity v_r

$$\vec{D}_B = D_{Bx}\vec{i} + D_{By}\vec{j} = \frac{1}{2}\rho C_{DA} v_r (\dot{x}_r \vec{i} + \dot{y}_r \vec{j}) = \frac{1}{2}\rho C_{DA} v_r \vec{v}_r$$

This approach may also be used to approximate the drag for other blunt shapes for which the drag areas for different flow directions do not differ greatly, e.g., near-cubes or circular cylinders with length to diameter ratios of approximately 1.

In the second approach, D_{Bx} and D_{By} are taken as proportional to the squares of the components of the relative fluid velocities in these respective directions

$$D_{Bx} = \frac{1}{2}\rho C_{DAx} \dot{x}_r |\dot{x}_r| \tag{53a}$$

$$D_{By} = \frac{1}{2}\rho C_{DAy} \dot{y}_r |\dot{y}_r| \tag{53b}$$

This is a good approximation for long cylinders or thin disks with axes parallel to the x- or y-directions. In these cases, where there is a large difference between the drag areas, the drag in one direction is essentially pressure drag whereas the much smaller drag in the other direction is essentially due to fluid friction.

In the present program, the choice of whether to use Equation (52) or (53) to compute the drag is determined by the value of the ratio C_{DAx}/C_{DAy}. It was somewhat arbitrarily decided that in the range

$$0.5 \leq C_{DAx}/C_{DAy} \leq 2.0 \tag{54}$$

Equations (52a) and (52b) would be used to compute D_{Bx} and D_{By}. Outside this range, Equations (53a) and (53b) are used to compute D_{Bx} and D_{By}.

VARIABLE COEFFICIENTS FOR CIRCULAR DISK

When a body is executing dynamic oscillations such that it periodically traverses its own viscous wake, the added mass and drag coefficients are more correctly expressed as functions

[33]Walton, T.S. and H. Polachek, "Calculation of Transient Motion of Submerged Cables," Mathematical Tables and Other Aids to Computation, Vol. 14, No. 69, pp. 27-46 (Jan 1960).

of the dynamic motion. Drag coefficients are usually obtained for steady flow and added mass coefficients are often computed for an inviscid fluid. The reviews by Wiegel[34] and Holler[35] show that nearly all of the measurements of the dynamic coefficients for various bodies have been conducted for dynamic oscillation in one direction only and in the absence of any steady-state fluid velocity. Thus, the results from these studies should be used with caution in the present case where the cable system will generally undergo dynamic motions in both directions in the presence of a steady-state current profile.

For the particular case of a circular disk, which is commonly used in sonobuoy systems to damp out the motions of the lower acoustic units, the user may either employ the constant coefficient approach (described previously) or have the program internally compute the dynamic added mass and drag coefficients for the direction normal to the disk plane, as based on the experimental relationships given by Holler.[35] The coefficients are related to the dynamic motions as follows[35]

$$C_{DAn} = \frac{\pi d_B^2}{4} \frac{2.2}{\gamma} \tag{55a}$$

$$M_{BVn} = M_B + 1.2\gamma\rho d_B^2 = M_B + M_A \tag{55b}$$

$$\gamma = \sqrt{\beta} = \sqrt{\frac{\dot{n}^2}{\ddot{n} d_B}} \text{ for } 0.077 \leq \beta \leq 3.84$$

$$= \sqrt{3.84} = 1.96 \text{ for } \beta > 3.84$$

$$= \sqrt{0.077} = 0.278 \text{ for } \beta < 0.077$$

where n = direction normal to the disk plane, either x or y

M_A = added mass

$\dot{n}, \ddot{n}$ = the velocity and acceleration, respectively, of the disk in this direction, either $(\dot{x}, \ddot{x})$ or $(\dot{y}, \ddot{y})$

The above formulas show how the drag area and the added mass vary with β, which is a measure of the ratio of relative magnitudes of the velocity and acceleration. At low values of β, where the acceleration is much higher than the velocity (e.g., during the initial instants of

[34]Wiegel, R.L., "Oceanographical Engineering," Prentice Hall, Inc., Englewood Cliffs, N.J., (1964), Chapter 11.

[35]Holler, R.A., "Hydrodynamic Effects of Harmonic Acceleration," Naval Air Development Center Report AE-7120 (Jan 1972).

a body starting from rest), the formulas show that C_{DAn} has a high value and that the added mass is given by $M_A = \rho d_B^3/3$, the potential flow result. At the other extreme of high values of β, where the velocity is much higher than the acceleration, the added mass has a high value and the drag area is given by $C_{DAn} = 1.12\pi d_B^2/4$, the steady-state value.

The added mass and drag in the direction tangent to the disk plane, which are much smaller, are computed by the constant coefficient approach outlined previously.

DESCRIPTION OF COMPUTER PROGRAM

Program CABUOY consists of a main program and six subroutines.

MAIN PROGRAM

The main program accepts input data for the cable system, surface waves, current profile, and the initial conditions for the dynamic calculations. If a surface buoy is present, input data are read in by Subroutine BUOY, described below. Data may be entered in either English or metric units. A detailed description of input instructions is given later.

The program is currently written to accept up to 50 cable segments and 49 intermediate bodies. This number can be conveniently increased by changing a few DIMENSION and COMMON statements, but it should be noted that dynamic calculations for more than 50 nodes are likely to require prohibitively large amounts of computer time.

The main program prints out the input data and then calls on various subroutines to calculate the ocean wave spectrum, certain constants for the surface buoy, the steady-state configuration of the cable system, and finally the dynamic motions of the system at prescribed time intervals. The output from the steady-state and dynamic calculations are also printed by this program.

SUBROUTINE STAT

This subroutine defines the five steady-state differential equations, (1) to (5), for the cable.

SUBROUTINE DYNA

This subroutine defines the dynamic differential equations, (36) and (37), for each of the M nodes. For cases where a buoy is present, this subroutine also defines the three differential equations of motion for the surface buoy, namely (23) to (25).

SUBROUTINE CUR

This subroutine furnishes the steady-state current profile relative to the cable system. For a free-floating cable system, this would be the actual current profile minus the drift velocity of the cable system. For a given value of the vertical distance y, this subroutine linearly interpolates between the input velocities which are read in as a function of y. For cases where the given value of y is greater (less) than the largest (smallest) value of y which is read in, the subroutine takes the velocity to be the value at the largest (smallest) algebraic value of y which is read in.

SUBROUTINE SPECT

This subroutine is employed when the user wishes the program to internally generate the surface wave components. In this case, the subroutine defines the amplitudes of the surface wave components by using the Pierson-Moskowitz energy sea spectrum, Equation (18). Provision is left at the end of the subroutine for implementing other forms for the sea spectrum.

SUBROUTINE BUOY

This subroutine is used when a surface buoy is present. After reading input data for the surface buoy, the subroutine calculates the various buoy geometrical and added inertia coefficients which appear in Equations (27) to (35). It concludes by calculating the steady-state pitch angle of the buoy, in the absence of any dynamic excitation due to surface waves.

SUBROUTINE ITERA

This subroutine is used for boundary value cases when iteration schemes are required to obtain the steady-state configuration of the cable system. It contains iteration schemes which are applicable for free-floating cable systems and a cable of given length moored in a given ocean depth. Provision is made at the end of the subroutine for implementing iteration schemes for other applications.

SUBROUTINE KUTMER

This subroutine uses the Kutta-Merson method to numerically integrate the steady-state differential equations defined in Subroutine STAT and the dynamic differential equations of

motion defined in Subroutine DYNA. The subroutine automatically reduces the integration step size until specified error criteria are met.

INPUT INSTRUCTIONS

READ STATEMENTS

Input data are entered into the program by means of the following READ statements contained in Program MAIN and Subroutine BUOY. These statements are given numbers simply for identification purposes.

MAIN Program

READ (5,1) NCASES	Card 1
DO 1000 MC = 1, NCASES	
READ (5,301) TITLE	Card 2
READ (5,1) NSM, NSW, NCAB, NCUR, ITER, MTRC	Card 3
READ (5,2) (FSM (K), K = 1, NSM)	Card 4
READ (5,2) (AXSM (K), K = 1, NSM)	Card 5
READ (5,2) (AYSM (K), K = 1, NSM)	Card 6
READ (5,2) (FIDSM (K), K = 1, NSM)	Card 7
READ (5,2) (ASW (K), K = 1, NSW)	Card 8
READ (5,2) (FRSW (K), K = 1, NSW)	Card 9
READ (5,2) (FIDSW (K), K = 1, NSW)	Card 10
READ (5,2) RHO, SUBM, TWX, TIY, CDASX, AMC, AFAC, TMIN	Card 11
READ (5,2) TINV1, DT1, TOTT, DT2, DIR, TBH, TBYMX	Card 12
READ (5,3) (FLC (K), K = 1, NCAB)	Card 13
READ (5,2) (DCI (K), K = 1, NCAB)	Card 14
READ (5,2) (CDN (K), K = 1, NCAB)	Card 15
READ (5,2) (CDT (K), K = 1, NCAB)	Card 16
READ (5,2) (WC (K), K = 1, NCAB)	Card 17
READ (5,4) (CM (K), K = 1, NCAB)	Card 18
READ (5,3) (TREF (K), K = 1, NCAB)	Card 19
READ (5,5) (C1 (K), K = 1, NCAB)	Card 20
READ (5,2) (C2 (K), K = 1, NCAB)	Card 21
READ (5,2) (CINT (K), K = 1, NCAB)	Card 22
READ (5,2) (WBD (K), K = 1, NCAB)	Card 23
READ (5,2) (CDABX (K), K = 1, NCAB)	Card 24
READ (5,2) (CDABY (K), K = 1, NCAB)	Card 25
READ (5,2) (XMBV (K), K = 1, NCAB)	Card 26
READ (5,2) (YMBV (K), K = 1, NCAB)	Card 27
READ (5,3) (YY (I), I = 1, NCUR)	Card 28
READ (5,3) (CCK (I), I = 1, NCUR)	Card 29
READ (5,2) (PHID (I), I = 1, NCAB)	Card 30

```
      READ (5,3)  (TENI (I), I = 1, NCAB)                             Card 31
      READ (5,2)  (XPI (I), I = 1, NCAB)                              Card 32
      READ (5,2)  (YPI (I), I = 1, NCAB)                              Card 33
 1000 CONTINUE
```

The corresponding FORMAT statements are:

```
    1 FORMAT  (24I3)
    2 FORMAT  (8F10.4)
    3 FORMAT  (8F10.2)
    4 FORMAT  (8F10.6)
    5 FORMAT  (8F10.0)
  301 FORMAT  (20A4)
```

Subroutine BUOY

```
      READ (5,1)  CDASY, WAS, RWY, RTX, RTY, YCG, BIN                 Card 34
      READ (5,1)  XSI, ZETI, SYDI, XPSI, ZTPI, SYPDI                  Card 35
```

The corresponding FORMAT statement is:

```
    1 FORMAT  (8F10.4)
```

DEFINITION OF INPUT VARIABLES FOR MAIN PROGRAM

NCASES	Number of cases, NCASES $\geqslant 1$
TITLE	Title
NSM[2]	Number of surface motion components, $1 \leqslant$ NSM $\leqslant 20$
NSW[3]	Number of surface wave components, $1 \leqslant$ NSW $\leqslant 20$
NCAB	Number of cable segments, $2 \leqslant$ NCAB $\leqslant 50$
NCUR	Number of current profile points, $2 \leqslant$ NCUR $\leqslant 10$
MTRC	MTRC $\leqslant 0$ if input data are entered in English units; MTRC $\geqslant 1$ if input data are entered in metric units
ITER	Iteration index
FSM(K)[2] AXSM(K)[2]	$x_{SM} = \sum_{k=1}^{NSM} AXSM(K)*\cos(-2\pi* FSM(K)*t + FIDSM(K)*\pi/180.)$
AYSM(K)[2] FIDSM(K)[2]	$y_{SM} = \sum_{k=1}^{NSM} -AYSM(K)*\sin(-2\pi* FSM(K)*t + FIDSM(K)*\pi/180.)$
ASW(K)[3]	$x_{SW} = \sum_{k=1}^{NSW} ASW(K)*\cos(-2\pi* FRSW(K)*t + FIDSW(K)*\pi/180.)$

FRSW(K)[3] FIDSW(K)[3]	$y_{SW} = \sum_{k=1}^{NSW} -ASW(K)*\sin\ (-2\pi*\ FRSW(K)*t + FIDSW(K)*\pi/180.)$
RHO	Fluid density in slugs/feet^3 (kilograms/meters^3)
SUBM[4]	Submergence of top point of cable below free surface in feet (meters)
TWX[4]	Horizontal force acting at top of cable in pounds (newtons)
TIY	Vertical component of tension at top of cable in pounds (newtons)
CDASX[4]	Drag area of surface buoy perpendicular to the x-axis in feet^2 (meters^2)
AMC	Added mass coefficient of cable; AMC = 1.0 for round cable
AFAC	Cross-sectional area of cable = AFAC*$\pi d^2/4$; AFAC = 1.0 for round cable
TMIN	Minimum algebraic tension which can be supported by cable in pounds (newtons)
TINV1	Initial time interval in seconds for dynamic calculations
DT1	Time step in seconds for which printout is desired for $0 \leq t \leq$ TINV1
TOTT	Total time in seconds for which dynamic calculations are desired
DT2	Time step in seconds for which printout is desired for TINV1 $< t \leq$ TOTT
DIR	DIR < 0. if initial conditions are prescribed at the bottom (towing cable case); otherwise DIR $\geq$ 0
TBH	Applied force in pounds (newtons) on lower weight, body NCAB-1, in x-direction
TBYMX	Maximum absolute value in pounds (newtons) of tension in cable just below buoy; for buoy-cable system, set TBYMX equal to a large number, say, 99999
FLC(K)	Length of Kth cable segment in feet (meters)
DCI(K)	Diameter of Kth cable segment in inches (centimeters)
CDN(K)	Normal drag coefficient of Kth cable segment
CDT(K)	Tangential drag coefficient of Kth cable segment
WC(K)	Weight in fluid in pounds/foot (newtons/meter) of Kth cable segment at the reference cable tension
CM(K)	Mass of Kth cable segment in slugs/foot (kilograms/meter) at the reference cable tension
TREF(K)	Reference tension in pounds (newtons) of Kth cable segment
C1(K)[5], C2(K), CINT(K)	Tension = TREF(K) + C1(K)*$\epsilon^{C2(K)}$ + CINT(K)*$\dot{\epsilon}$; for linearly elastic material, C1(K) = AE and C2(K) = 1
WBD(K)	Weight in fluid of Kth body in pounds (newtons)
CDABX(K)[6], CDABY(K)[6]	Drag area of Kth body in feet^2 (meters^2) for flow in (x, y) directions
XMBV(K)[6], YMBV(K)[6]	Virtual mass (mass + added mass) in slugs (kilograms) of Kth body in (x, y) directions

YY(I)[7]	Value of y in feet (meters)
CCK(I)	Value of current in knots (meters/second) at y = YY(I)
PHID(I)[8]	Initial value of ϕ of Ith cable segment in degrees
TENI(I)[8]	Initial value of tension of Ith cable segment in pounds (newtons)
XPI(I)	Initial value of $\dot{x}$ of Ith node in feet/second (meters/second)
YPI(I)	Initial value of $\dot{y}$ of Ith node in feet/second (meters/second)

DEFINITION OF INPUT VARIABLES FOR SURFACE BUOY

CDASY	Drag area for y-direction in feet^2 (meters^2)
WAS	Weight in air in pounds (newtons)
RWY	Vertical distance of wind loading center of pressure from buoy center of gravity YCG in feet (meters)
RTX, RTY	(x, y) distance of cable attachment point from YCG in feet (meters)
YCG	Submergence of center of gravity below the free surface under the action of its own weight in air WAS and the vertical component of the steady-state tension (−TIY) in feet (meters)
BIN	Moment of inertia in air about YCG in slug feet^2 (kilogram meters^2)
XSI, ZETI, SYDI[9]	Initial values of (x, ζ, ψ) in (feet, feet, degrees)(meters, meters, degrees), where ζ is the vertical displacement of the center of gravity from its equilibrium value YCG
XPSI, ZTPI, SYPDI	Initial values of $(\dot{x}, \dot{\zeta}, \dot{\psi})$ in (feet/second, feet/second, degrees/second) (meters/second, meters/second, degrees/second)

EXPLANATORY NOTES

1. ITER = 0, no iteration (prescribed initial steady-state conditions)
   1, free-floating cable system
   2, moored cable with given length in given depth
   3, iteration scheme to be programmed by user

2. For 1000. $\leq$ FSM(1) < 2000., the program makes the prescribed surface motion components equal to the surface wave components by setting AXSM(K) = AYSM(K) = ASW(K), FSM(K) = FRSW(K), and FIDSM(K) = FIDSW(K) for K = 1 to K = NSM; the program automatically sets NSM = NSW.

For 2000. $\leq$ FSM(1) < 3000., the program accepts input data for a spar buoy and considers AXSM(K) to be the cross-sectional area of the buoy in feet^2 (meters^2) at depth AYSM(K) feet (meters) below the free surface. AYSM(1) = 0. and AYSM(NSM) = total draft under the combined action of buoy weight in air and the vertical component of the

steady-state tension. NSM should be an odd number. The input values for FIDSM(K) may take on any values such as, say, 0.

For FSM(1) > 3000., the program accepts input data for a spheroidal buoy and considers AXSM(1) to be the radius of the buoy cross section at the free surface and AYSM(1) to be the total draft. The rest of the input values of AXSM(K) and AYSM(K) as well as all of the FIDSM(K) may take on any values, e.g., 0.

3. For ASW(1) > 1000., the program computes the amplitude of the ASW surface wave components by using the Pierson-Moskowitz sea spectrum. In these cases, the program considers the significant wave height in feet (meters) to be (ASW(1) - 1000.) and FRSW(1) and FRSW(2) to respectively be the lower and upper frequencies of the spectrum in cycles per second. The program internally generates the phases of the wave components by considering them to be uniformly separated by 360/NSW degrees. The phase of the lowest frequency component, in degrees, is taken to be the input value of FIDSW(1).

4. For the case of a surface buoy (FSM(1) $\geq$ 2000.), the program calculates the drag acting on the surface buoy due to the ocean current by taking the value of the ocean current SUBM feet (meters) below the free surface. Thus, 0 $\leq$ SUBM $\leq$ total draft.

The total horizontal force at the top point of the cable TIX = TWX + (1/2)ρ* CDASX* CCF (SUBM)* ABS (CCF (SUBM)). In cases where there is no surface buoy (i.e., prescribed surface motion), TWX and/or CDASX may be set equal to zero. For cases of a surface buoy, TWX represents the wind loading on the buoy in pounds (newtons).

5. For free-floating and towing cables where the last (K = NCAB) cable connecting the lower weight to the ocean bottom is fictitious, read in a value for C1(NCAB) less than 0.0001 pounds (0.0004 newtons). In these cases, the program sets DC1(NCAB) = CDN(NCAB) = CDT(NCAB) = WC(NCAB) = CM(NCAB) = CINT(NCAB) = 0, FLC(NCAB) = 2 * FLC(NCAB - 1), and C2(NCAB) = 1.

6. If CDABX(K) is negative, the program considers the body to be a circular disk with plane perpendicular to the x-axis and calculates drag and added mass forces by using the formulation given in Equation (55). In these cases, CDABX(K) is the negative of the actual drag area and XMBV(K) is the mass (not the virtual mass) of the disk. In these cases, CDABY(K) and YMBV(K) should be positive and retain the definitions given previously. Similar remarks apply if CDABY(K) is read in as a negative number except that the plane of the disk is now perpendicular to the y-axis.

7. When ITER = 2, the porgram takes YY(NCUR) to be the ocean depth.

8. For |PHID(1)| $\geq$ 360., the program takes the initial values of the angle and tension of each cable segment to correspond to their respective steady-state values at the midpoint of

each segment. These steady-state values have been previously calculated by the program. This approach will minimize transient dynamic effects. In these cases, input values for the remaining PHID(K) as well as all of the TENI(K) may be arbitrary, e.g. 0.

9. For SYDI $\geqslant$ 360., the program sets the initial value for buoy inclination ψ equal to the steady-state value of ψ, which has previously been calculated by the program. This will tend to minimize transient dynamic motions of the surface body.

PROGRAM STORAGE AND TIME REQUIREMENTS

On the CDC 6700 currently in use at the Center, the program requires a memory of approximately 47,200 octal words to load and 33,700 octal words to execute. Compilation time is approximately 23 seconds. Execution time for a particular case depends on a large number of factors, the most important of which include the tension-strain relation of the cable, the number of cable nodes, the frequencies of the exciting surface waves and the prescribed surface motion (if any), and the amount of time over which the dynamic motions are desired. Table 2 shows the computer execution time ET and cost for all of the sample problems presented in the following chapter. A computer priority (CP) of P2 indicates overnight priority whereas P3 is the standard daytime priority at the DTNSRDC Computer Center.

TABLE 2 – COMPUTER EXECUTION TIMES AND COST FOR ALL THE SAMPLE PROBLEMS

Prob.	NCAB-1	C1 lb (4.45N)	C2	ET sec	CP	Total Cost $
1A	4	2.4×10^1	1.0	61.7	P2	9.93
1B	4	2.4×10^2	1.0	57.8	P2	9.56
1C	4	2.4×10^3	1.0	62.4	P2	9.99
1D	4	2.4×10^4	1.0	85.0	P2	12.00
1E	4	2.4×10^5	1.0	250.0*	P2	28.00*
1F	4	2.4×10^3	0.5	1000.0*	P2	100.00*
1G	4	2.4×10^3	2.0	55.2	P2	8.93
2A	1	2.4×10^3	1.0	9.3	P2	5.15
2B	2	2.4×10^3	1.0	25.1	P2	6.60
2C	4	2.4×10^3	1.0	62.4	P2	9.99
2D	8	2.4×10^3	1.0	180.0*	P2	20.00*
2E	15	2.4×10^3	1.0	600.0*	P2	60.00*
3A	4	2.0×10^1	1.0	90.0**	P3	15.00**
3B	4	2.0×10^1	1.0	100.0**	P3	16.00**
3C	4	2.0×10^1	1.0	100.0**	P3	16.00**
4A	4	****	****	82.6	P3	14.27
4B	4	****	****	74.2	P2	11.10
4C***	4	****	****	100.0*	P3	16.00*

* Extrapolated to 50 sec of dynamic motion
** Extrapolated to 20 sec of deployment time
*** Six surface wave components
**** See Figure 11

SAMPLE PROBLEMS

Input cards are listed for the four sample problems presented to illustrate use of the program. Representative portions of the program output are listed for one of the cases of Problem 1, but only some final results are shown for the other three problems.

PROBLEM 1 – UNIFORM CABLE WITH VARIOUS TENSION-STRAIN RELATIONS

Problem: Compute the dynamic behavior of a cable suspended from an ocean platform in the presence of a uniform current of 1 knot in the +x-direction for different values of the elastic constants C_1 and C_2 appearing in Equation (47)

Case	C1 lb (4.45 N)	C2
A	2.4 x 10	1.0
B	2.4 x 10^2	1.0
C	2.4 x 10^3	1.0
D	2.4 x 10^4	1.0
E	2.4 x 10^5	1.0
F	2.4 x 10^3	0.5
G	2.4 x 10^3	2.0

The fixed surface motion, surface wave, cable, and lower body parameters are as follows:

Surface motion = surface wave:

number of components	1
frequency	0.1 cps
amplitude in x- and y-directions	10 ft (3.05 m)
phase angle	0 deg

Cable:

length	1000 ft (305 m)
diameter	0.2 in. (0.508 cm)
normal drag coefficient	1.4
tangential drag coefficient	0.02
weight in fluid	0.01 lb/ft (0.146 N/m)
mass	0.001 slugs/ft (0.0478 kg/m)
reference tension	25 lb (111.2 N)
internal damping coefficient	0

Lower weight:

weight in fluid	20 lb (89 N)
drag area in x-direction	0.3 ft^2 (0.0279 m^2)
drag area in y-direction	0.3 ft^2 (0.0279 m^2)
virtual mass in x-direction	1.0 slugs (14.6 kg)
virtual mass in y-direction	1.0 slugs (14.6 kg)

Fluid density: 1.94 slugs/ft^3 (1000.6 kg/m^3)

Represent the cable by four equal segments, not including the fictitious cable segment below the lower weight. Dynamic motions are desired for a total of five cycles of the surface motions, i.e. 50 sec. For the initial interval of 10 sec, print out the transient motions every

0.25 sec. For the final 40 sec, increase the printout interval to 1.0 sec. Let the cable start from rest with the initial angle and tension of each segment equal to the steady-state values.

Solution: The data cards for this problem are listed in Table 3. The cards which are the same for all the cases are listed at the top of the table. The cards for the title and the elastic constants C1 and C2, which differ for each case, are listed at the bottom of the table. The symbol b denotes a blank in this and subsequent tables which list data cards for the sample problems. Also, Column 1, 11, 21, 31, 41, 51, 61, and 71 have been indicated since most of the data start in these columns.

TABLE 3 – INPUT DATA FOR SAMPLE PROBLEM 1

	1	11	21	31	41	51	61	71
Card 1	bb1							
Card 3	bb1bb1bb5bb2bb0							
Card 4	0.1							
Card 5	10.0							
Card 6	10.0							
Card 7	0.							
Card 8	10.0							
Card 9	0.1							
Card 10	0.							
Card 11	1.94	0.	0.	-50.	0.	1.0	1.0	0.
Card 12	10.	0.25	50.	1.0	-1.0	0.	99999.	
Card 13	250.	250.	250.	250.				
Card 14	0.2	0.2	0.2	0.2				
Card 15	1.4	1.4	1.4	1.4				
Card 16	0.02	0.02	0.02	0.02				
Card 17	0.01	0.01	0.01	0.01				
Card 18	0.001	0.001	0.001	0.001				
Card 19	25.	25.	25.	25.				
Card 22	0.	0.	0.	0.				
Card 23	0.	0.	0.	20.				
Card 24	0.	0.	0.	0.3				
Card 25	0.	0.	0.	0.3				
Card 26	0.	0.	0.	1.0				
Card 27	0.	0.	0.	1.0				
Card 28	0.	10000.						
Card 29	1.	1.						

TABLE 3 – (continued)

	1	11	21	31	41	51	61	71
Card 30	999.	0.	0.	0.				
Card 31	0.	0.	0.	0.				
Card 32	0.	0	0.	0.				
Card 33	0.	0.	0.	0.				
Card 2	bbb PROBLEM 1A, C1 = 24, C2 = 1							
Card 20	24.	24.	24.	24.				
Card 21	1	1.	1.	1.				
Card 2	bbb PROBLEM 1B, C1 = 240, C2 = 1							
Card 20	240.	240.	240.	240.				
Card 21	1.	1.	1.	1.				
Card 2	bbb PROBLEM 1C, C1 = 2400, C2 = 1							
Card 20	2400.	2400.	2400.	2400.				
Card 21	1.	1.	1.	1.				
Card 2	bbb PROBLEM 1D, C1 = 24000, C2 = 1							
Card 20	24000.	24000.	24000.	24000.				
Card 21	1.	1.	1.	1.				
Card 2	bbb PROBLEM 1E, C1 = 240000, C2 = 1							
Card 20	240000.	240000.	240000.	240000.				
Card 21	1.	1.	1.	1.				
Card 2	bbb PROBLEM 1F, C1 = 2400, C2 = 0.5							
Card 20	2400.	2400.	2400.	2400.				
Card 21	0.5	0.5	0.5	0.5				
Card 2	bbb PROBLEM 1G, C1 = 2400, C2 = 2							
Card 20	2400.	2400.	2400.	2400.				
Card 21	2.0	2.0	2.0	2.0				

Table 4 shows the first six and the last two pages of the computer output for Problem 1D. The pages which have been left out simply contain output for the dynamic motions for intermediate time intervals. Table 4 shows that the first page of the output lists a table of conversion from English to metric units. The second page lists the input data. For the present case of a suspended cable, where the initial conditions are known at the lower body, two integrations are performed for the steady-state configuration (see section on Initial Value Cases). The results of these two integrations are given in the next two pages. The remainder of the output is a listing of the dynamic displacements, velocities, and accelerations of the surface waves, upper cable point, and each node at the prescribed time intervals. The output also lists the angle, angular velocity, tension, strain, and strain rate of each cable segment.

TABLE 4 – PROGRAM OUTPUT FOR PROBLEM 1D

```
CONVERSION FROM FNGLISH UNITS TO METRIC UNITS

            ENGLISH    METRIC
            1 INCH=    2.540 CM
            1 FOOT=    0.3048 METERS
            1 SQ FT=   0.09290 SQ M
            1 CU FT=   0.02831 CU M
            1 POUND=   4.452 NEWTONS
            1 SLUG=    14.607 KGM
            1 SECOND=  1 SECOND
            1 KNOT=    0.5144M/SEC
```

TABLE 4 – (continued)

PROBLEM 1D,C1=24000,C2=1

LISTING OF ENVIRONMENTAL AND CABLE-BUOY CHARACTERISTICS

OCEAN CONDITIONS

SURFACE WAVE-	FREQ(CPS)	AMPL(FT)	PHASE(D)	WL(FT)	WK(1/FT)
	.10	10.00	0.00	512.48	.0123

CURRENT PROFILE	DEPTH(FT)	CURR(KT)
	0.00	1.00
	10000.00	1.00

FLUID DENSITY= 1.9400 SL/CUFT

SURFACE MOTION-FREQ(CPS)	X-A(FT)	Y-A(FT)	PHASE(DEG)
.1000	10.0000	10.0000	0.0000

GENERAL CABLE CHARACTERISTICS

AM COEFF	AREA FAC	T MIN(LB)
1.0000	1.0000	0.00

CABLE PROPERTIES / BODY PROPERTIES

NUM	LEN(FT)	DIAM(IN)	CDN	CDT	W(LB/F)	M(SL/F)	T REF(LB)	C1(LB)	EXP C2	CINT(LB)	CDAX(F2)	CDAY(F2)	WT(LB)	XVM(SL)	YVM(SL)
1	250.00	.2000	1.4000	.0200	.0100	.001000	25.00	24000.	1.0000	0.0000	0.000	0.000	0.000	0.0000	0.0000
2	250.00	.2000	1.4000	.0200	.0100	.001000	25.00	24000.	1.0000	0.0000	0.000	0.000	0.000	0.0000	0.0000
3	250.00	.2000	1.4000	.0200	.0100	.001000	25.00	24000.	1.0000	0.0000	0.000	0.000	0.000	0.0000	0.0000
4	250.00	.2000	1.4000	.0200	.0100	.001000	25.00	24000.	1.0000	0.0000	.300	.300	20.000	1.0000	1.0000
5	500.00	0.0000	0.0000	0.0000	0.00000	.000000	0.00	0.	1.0000	0.0000	0.000	0.000	0.000	0.0000	0.0000

X-LOAD ON BOT WT= 0.0000 LB

SURFACE BUOY CHARACTERISTICS

SUBM(FT)	WIND LD(LB)	CDAX(FTSQ)	MAX TEN(LB)
0.0000	0.0000	0.0000	99999.0000

INITIAL VALUES AT TOP OF CABLE

XA= 10.0000 YA= 0.0000 XVA= 0.0000 YVA= 6.2032

TABLE 4 – (continued)

RUN NUMBER 1

STEADY-STATE CONFIGURATION

TIX= .83 TIY= 20.00 DIRECTION= -1.08

NODE	S REF(FT)	S STR(FT)	X(FT)	Y(FT)	TEN(LB)	PHIS(DEG)
0	0.00	0.00	10.00	0.00	20.02	177.63
4	125.00	124.98	-17.97	-121.13	21.24	157.34
4	250.00	249.96	-80.72	-228.86	22.34	143.28
3	250.00	249.96	-80.72	-228.86	22.34	143.28
3	375.00	374.95	-163.82	-322.84	23.33	134.02
3	500.00	499.94	-258.39	-403.68	24.21	127.99
2	500.00	499.94	-258.39	-403.68	24.21	127.99
2	625.00	624.94	-359.72	-476.83	25.02	123.92
2	750.00	749.94	-465.24	-543.82	25.77	121.07
1	750.00	749.94	-465.24	-543.82	25.77	121.07
1	875.00	874.95	-573.50	-606.31	26.48	119.82
1	1000.00	999.96	-683.63	-665.45	27.16	117.52
0	1000.00	999.96	-683.63	-665.45	27.16	117.52

X-COMPONENT OF TENSION= -24.09 LB
Y-COMPONENT OF TENSION= -12.55 LB

REVISED VALUE OF WIND LD= -24.0654 LB

INITIAL VALUES AT TOP OF CABLE
XA= 10.0000 YA= 0.0000 XVA= 0.0000 YVA= 6.2832

TABLE 4 – (continued)

RUN NUMBER 1

STEADY-STATE CONFIGURATION

TIX= -24.09 TIY= -12.55 DIRECTION= 1.00

NODE	S REF(FT)	S STR(FT)	X(FT)	Y(FT)	TEN(LB)	PHIS(DEG)
0	0.00	0.00	10.00	0.00	27.16	-62.48
1	125.00	125.01	120.13	59.14	26.48	-60.98
1	250.00	250.02	228.39	121.63	25.77	-58.93
1	250.00	250.02	228.39	121.63	25.77	-58.93
2	375.00	375.02	333.91	188.62	25.02	-56.08
2	500.00	500.02	435.24	261.77	24.21	-52.01
2	500.00	500.02	435.24	261.77	24.21	-52.01
3	625.00	625.01	529.81	343.41	23.33	-45.98
3	750.00	750.00	612.91	436.60	22.34	-36.80
3	750.00	750.00	612.91	436.60	22.34	-36.80
4	875.00	874.98	675.66	544.32	21.24	-22.66
4	1000.00	999.96	703.63	665.45	20.02	-2.37
4	1000.00	999.96	703.63	665.45	.00	93.41
5	1250.00	1279.45	424.63	648.81	.00	93.41
5	1500.00	1558.95	145.63	632.17	.00	93.41
5	1500.00	1558.95	145.63	632.17	.00	93.41

X-COMPONENT OF TENSION= -.00 LB
Y-COMPONENT OF TENSION= -.00 LB

CABLE INITIAL CONDITIONS

NODE	PHI(DEG)	TEN(LB)	X(FT)	Y(FT)	XV(FT/S)	YV(FT/S)
1	-63.9757	26.48	228.62	121.30	0.0000	0.0000
2	-56.0834	25.02	436.08	260.80	0.0000	0.0000
3	-45.9844	23.33	615.85	434.50	0.0000	0.0000
4	-22.6616	21.24	712.16	665.16	0.0000	0.0000
5	93.4133	.00	154.16	631.88	0.0000	0.0000

TIME INFORMATION

INITIAL TIME INTERVAL= 10.0000 SEC TIME STEP= .2500 SEC
TOTAL TIME= 50.0000 SEC TIME STEP= 1.0000 SEC

TABLE 4 – (continued)

COMPUTED CABLE SYSTEM MOTIONS AND TENSIONS

NUM	T(SEC)	DT(SEC)	X(FT)	Y(FT)	XP(FT/S)	YP(FT/S)	XPP(F/SS)	YPP(F/SS)	TEN(LB)	FI(DEG)	FIP(D/S)	STRAIN	STP(1/S)
WAVE	.2500	.003906	9.00	1.56	-.9029	6.2058	-3.0992	-.6176					
0	.2500	.003906	9.00	1.56	-.9029	6.2058			17.63	-61.38	-1.70	-.000315	.000950
1	.2500	.003906	229.26	121.29	2.7690	-.1749	-11.1273	-6.4133	10.05	-55.99	.63	-.000590	.001596
2	.2500	.003906	436.36	261.06	2.0476	1.6085	-11.0352	-10.2609	5.50	-45.90	.07	-.000009	-.000274
3	.2500	.003906	615.99	434.64	1.7031	1.7036	4.7333	-1.1613	4.75	-22.64	.23	-.000044	-.006929
4	.2500	.003906	712.16	665.10	.1043	.5736	5.0006	12.2471	.00	93.41	.06	.117973	.000436
WAVE	.5000	.001953	9.51	3.09	-1.9416	5.9757	-3.7546	-1.2200					
0	.5000	.001953	9.51	3.09	-1.9416	5.9757			11.24	-61.01	-1.76	-.000573	.000117
1	.5000	.001953	229.73	121.12	1.7157	-.7065	9.[illegible]461	5.7000	13.45	-55.09	.42	-.000401	.004300
2	.5000	.001953	436.62	261.26	1.6059	1.3270	17.0053	15.9003	10.02	-45.90	.12	-.000291	.003242
3	.5000	.001953	616.34	434.93	1.0104	2.2026	2.7311	7.1057	19.21	-22.59	.19	-.000241	.000321
4	.5000	.001953	712.36	665.69	1.0099	2.6691	-.4345	-1.3346	.00	93.67	.27	.110443	.002499
WAVE	.7500	.015625	8.91	4.54	-2.0525	5.5984	-3.5176	-1.7923					
0	.7500	.015625	8.91	4.54	-2.0525	5.5984			40.71	-62.25	-1.74	.000655	-.000240
1	.7500	.015625	230.30	121.03	.6373	-1.1672	-14.5216	-7.2067	32.31	-55.70	.37	.000305	.005235
2	.7500	.015625	437.00	261.67	.0005	.9002	-19.9169	-14.6330	24.52	-45.95	.07	-.000020	.003793
3	.7500	.015625	616.76	435.49	1.2762	1.7005	-6.7719	-6.9015	20.04	-22.55	.12	-.000173	.001001
4	.7500	.015625	712.62	666.33	.9914	2.4159	-.9024	-2.2904	.00	93.53	.24	.119043	.002276
WAVE	1.0000	.003906	0.09	5.00	-3.6932	5.0032	-3.1939	-2.3205					
0	1.0000	.003906	0.09	5.00	-3.6932	5.0032			46.04	-62.60	-1.69	.000077	.003140
1	1.0000	.003906	230.40	120.73	.3920	-1.1130	-1.7409	.0075	42.90	-55.69	.35	.000749	.002296
2	1.0000	.003906	437.05	261.75	.0077	.4679	-2.1330	-1.2960	40.63	-45.94	.04	.000651	.000999
3	1.0000	.003906	616.03	435.70	.0507	.7026	-4.3969	-7.2781	36.07	-22.55	-.05	.000461	-.003075
4	1.0000	.003906	712.77	666.69	-.1256	-.1931	-5.4790	-13.0763	.00	93.57	.02	.119371	-.000275
WAVE	1.2500	.007813	7.07	7.07	-4.4429	4.4429	-2.7915	-2.7915					
0	1.2500	.007813	7.07	7.07	-4.4429	4.4429			50.20	-63.09	-1.63	.001050	-.003660
1	1.2500	.007813	230.24	120.33	-2.0316	-2.3301	-2.9557	-1.3702	43.65	-55.62	.19	.000777	.000541
2	1.2500	.007813	436.74	261.60	-2.3040	-1.5741	-1.0034	-1.6221	39.03	-45.97	-.21	.000610	.000610
3	1.2500	.007813	616.59	435.46	-1.6506	-2.1142	-3.7315	-5.0021	32.24	-22.50	-.16	.000302	.000626
4	1.2500	.007813	712.62	666.36	-.9355	-2.2422	-2.0039	-7.6023	.00	93.53	-.22	.119047	-.002144
WAVE	1.5000	.015625	5.00	0.09	-5.0032	3.6932	-2.3205	-3.1939					
0	1.5000	.015625	5.00	0.09	-5.0032	3.6932			47.34	-63.49	-1.52	.000931	.000070
1	1.5000	.015625	229.79	119.00	-2.1106	-2.2264	-6.1964	-2.7707	39.17	-55.50	.13	.000590	-.000040
2	1.5000	.015625	436.14	261.19	-2.4467	-1.7535	-6.7735	-6.2332	33.57	-46.03	-.26	.000357	-.000917
3	1.5000	.015625	616.13	434.83	-1.0297	-2.7232	-.5994	-3.2643	26.50	-22.63	-.16	.000066	-.002231
4	1.5000	.015625	712.32	665.61	-1.3950	-3.5087	.0909	-.1910	.00	93.46	-.35	.118341	-.003200
WAVE	1.7500	.031250	4.54	6.91	-5.5984	2.0525	-1.7923	-3.5176					
0	1.7500	.031250	4.54	6.91	-5.5984	2.0525			43.66	-63.05	-1.37	.000777	-.000032
1	1.7500	.031250	229.12	11[illegible].10	-2.9610	-2.5355	.4640	1.1060	36.77	-55.56	.05	.000490	.000470
2	1.7500	.031250	435.41	260.63	-2.9759	-2.3037	2.9253	2.4303	33.07	-46.10	-.29	.000369	.000542
3	1.7500	.031250	615.62	434.03	-1.9972	-3.1255	-.0542	1.0020	27.52	-22.67	-.16	.000105	-.000315
4	1.7500	.031250	711.98	664.75	-1.3609	-3.4732	-.4062	-1.0106	.00	93.37	-.35	.117563	-.003142
WAVE	2.0000	.031250	3.09	9.51	-5.9757	1.9416	-1.2200	-3.7546					
0	2.0000	.031250	3.09	9.51	-5.9757	1.9416			50.53	-64.17	-1.17	.001064	.000577
1	2.0000	.031250	22[illegible]35	110.56	-3.6107	-2.6125	-4.2274	-1.2244	40.33	-55.56	-.0[illegible]	[illegible]000639	.001140
2	2.0000	.031250	43[illegible]5	260.05	-3.2055	-2.5020	-3.0243	-2.4069	35.12	-46.10	-.32	.000422	.000042
3	2.0000	.031250	615.11	433.22	-2.1014	-3.4292	-1.4136	-1.9201	27.50	-22.71	-.10	.000104	.006651
4	2.0000	.031250	711.63	663.06	-1.4097	-3.5750	-.3070	-.7355	.00	93.28	-.36	.116766	-.003224

TABLE 4 – (continued)

WAVE	2.2500	.031250	1.56	9.88	-6.2058	.9829	-.6176	-3.0992					
0	2.2500	.031250	1.56	9.82	-6.2058	.9829			56.10	-44.43	-.94	.001296	.001329
1	2.2500	.031250	227.30	117.93	-4.1318	-2.5023	-2.3069	.0657	45.66	-55.50	-.12	.000861	.000990
2	2.2500	.031250	433.77	259.36	-3.6420	-2.8594	-1.8911	-1.4997	40.38	-46.26	-.33	.000641	.000694
3	2.2500	.031250	614.52	432.31	-2.5094	-3.7918	-1.3693	-1.0097	31.94	-22.76	-.22	.000289	.000097
4	2.2500	.031250	711.25	662.91	-1.6329	-4.1337	-1.1049	-2.0420	.00	93.19	-.41	.115989	-.003721
WAVE	2.5000	.031250	.00	10.00	-6.2832	.0000	-.0000	-3.9670					
0	[illegible] 5000	.031250	.00	10.00	-6.2832	.0000			61.99	-64.66	-.69	.001561	.000495
1	2.5000	.031250	226.25	117.26	-4.8026	-2.6659	-2.2682	.0337	49.97	-55.62	-.21	.001040	.000638
2	2.5000	.031250	432.79	258.50	-4.2236	-3.3497	-1.2950	-1.0990	44.05	-46.35	-.39	.000794	.000639
3	2.5000	.031250	613.03	431.27	-2 [illegible]197	-4.4892	-1.4263	-2.1791	34.40	-22.82	-.25	.000395	.000445
4	2.5000	.031250	710.81	661.80	-1.8094	-4.7979	-1.0948	-2.0271	.00	93.08	-.40	.114909	-.004208
WAVE	2.7500	.031250	-1.56	9.88	-6.2058	-.9829	.6176	-3.0992					
0	2.7500	.031250	-1.56	9.88	-6.2058	-.9829			65.32	-64.77	-.42	.001680	.000391
1	2.7500	.031250	224.98	116.60	-5.3407	-2.5902	-2.0700	.1360	52.51	-55.60	-.30	.001146	.000326
2	2.7500	.031250	431.69	257.71	-4.5340	-3.6275	-1.4296	-1.3160	46.03	-46.46	-.43	.000876	.000180
3	2.7500	.031250	613.04	430.00	-3.1996	-4.9664	-.9090	-1.6923	35.04	-27.00	-.27	.000452	.000069
4	2.7500	.031250	710.31	660.52	-2.1223	-5.4022	-.6862	-1.7060	.00	92.95	-.54	.113769	-.004795
WAVE	3.0000	.031250	-3.09	9.51	-5.4757	-1.9416	1.2200	-3.7546					
0	3.0000	.031250	-3.09	9.51	-5.4757	-1.9416			66.37	-64.04	-.14	.001724	.000056
1	3.0000	.031250	223.59	115.96	-5.7077	-2.4795	-.9657	.6984	53.45	-55.77	-.30	.001106	.000003
2	3.0000	.031250	430.32	256.77	-4.7537	-3.8467	-.3222	-.4038	46.94	-46.57	-.45	.000914	.000077
3	3.0000	.031250	612.24	428.88	-3.3740	-5.2734	-.3958	-.6395	36.52	-22.95	-.20	.000480	.000017
4	3.0000	.031250	709.76	659.12	-2.2557	-5.7426	-.4104	-1.0164	.00	92.81	-.50	.112533	-.005060
WAVE	3.2500	.062500	-4.54	8.91	-5.5984	-2.8525	1.7923	-3.5176					
0	3.2500	.062500	-4.54	8.91	-5.5984	-2.8525			66.25	-64.04	.15	.001719	-.000164
1	3.2500	.062500	222.14	115.37	-5.9079	-2.2898	-.6058	.0178	53.45	-55.87	-.45	.001106	-.000067
2	3.2500	.062500	429.33	255.88	-4.8156	-3.9314	-.0460	-.1086	46.87	-46.68	-.46	.000911	-.000040
3	3.2500	.062500	611.39	427.46	-3.4462	-5.4017	-.1225	-.2100	36.36	-23.02	-.20	.000473	-.000041
4	3.2500	.062500	709.19	657.66	-2.3108	-5.8912	-.1343	-.2703	.00	92.66	-.60	.111240	-.005179
WAVE	3.5000	.062500	-5.88	8.09	-5.0032	-3.6932	2.3205	-3.1939					
0	3.5000	.062500	-5.88	8.09	-5.0032	-3.6932			66.66	-64.77	.63	.001652	-.000356
1	3.5000	.062500	220.65	114.02	-5.9505	-2.0443	.0647	1.0753	52.60	-55.99	-.51	.001150	-.000212
2	3.5000	.062500	428.13	254.81	-4.7502	-3.9178	.4225	.2130	46.20	-46.08	-.45	.000803	-.000107
3	3.5000	.062500	610.52	426.11	-3.4301	-5.3919	.1910	.2715	35.08	-23.09	-.29	.000457	-.000143
4	3.5000	.062500	708.61	656.19	-2.3318	-5.9024	.0365	.1904	.00	92 51	-.60	.109952	-.005176
WAVE	3.7500	.062500	-7.07	7.07	-4.4429	-4.4429	2.7915	-2.7915					
0	3.7500	.062500	-7.07	7.07	-4.4429	-4.4429			61.00	-64.63	.69	.001533	-.000601
1	3.7500	.062500	219.17	114.35	-5.6709	-1.7650	.6425	1.2207	50.01	-56.13	-.55	.001075	-.00037[illegible]
2	3.7500	.062500	426.95	253.84	-4.6074	-3.0201	.0026	.5229	44.71	-46.91	-.44	.000021	-.000[illegible]6
3	3.7500	.062500	609.67	424.77	-3.3505	-5.2788	.4761	.6096	34.70	-23.16	-.27	.000400	-.000226
4	3.7500	.062500	708.03	654.72	-2.2991	-5.7033	.2181	.6642	.00	92.36	-.59	.100669	-.005072
WAVE	4.0000	.031250	-8.09	5.88	-3.6932	-5.0032	3.1939	-2.3205					
0	4.0000	.031250	-8.09	5.88	-3.6932	-5.0032			57.61	-64.43	.94	.001359	-.000802
1	4.0000	.031250	217.72	113.95	-5.6526	-1.4531	1.1720	1.2039	48.00	-56.27	-.50	.000950	-.000550
2	4.0000	.031250	425.83	252.91	-4.3495	-3.6524	1.2220	.8524	42.37	-47.02	-.41	.000724	-.000457
3	4.0000	.031250	608.85	423.40	-3.2008	-5.0525	.7770	1.1073	33.09	-23.22	-.25	.000337	-.000330
4	4.0000	.031250	707.46	653.30	-2.7204	-5.5652	.4100	1.1755	.00	92.22	-.57	.107424	-.004869
WAVE	4.[illegible]	.031250	-8.91	4.54	-2.8525	-5.5984	3.5176	-1.7923					
0	4[illegible]	.031250	-8.91	4.54	-2.8525	-5.5984			52.24	-64.16	1.17	.001135	-.000976
1	[illegible]	.031250	216.35	113.62	-5.2985	-1.1235	1.7341	1.3593	44.25	-56.42	-.60	.000802	-.000692
2	[illegible]	.031250	424.79	252.02	-3.9891	-3.3961	1.6530	1.1932	39.23	-47.12	-.38	.000593	-.000535
[illegible]	[illegible]00	.031250	608.00	422.26	-2.9466	-4.7140	1.1034	1.5870	30.02	-23.28	-.23	.000242	-.000424
4	4.2500	.031250	706.92	651.95	-2.0098	-5.2059	.6200	1.7046	.09	92.08	-.53	.104244	-.004555
WAVE	4.5000	.031250	-9.51	3.09	-1.9416	-5.9757	3.7546	-1.2200					
0	4.5000	.031250	-9.51	3.09	-1.9416	-5.9757			46.04	-63.85	1.36	.000877	-.001083
1	4.5000	.031250	215.89	113.3	-4.7958	-.7796	2.2396	1.4003	39.76	-56.57	-.60	.000615	-.000796
2	4.5000	.031250	423.05	251.21	-3.5274	-3.0603	2.0312	1.4909	35.43	-47.21	-.34	.000439	-.000672
3	[illegible].5000	.031250	607.37	421.33	-2.6495	-4.2562	1.4071	2.0693	20.05	-23.34	-.20	.000127	-.000492
4	4.5000	.031250	706.42	658.71	-1.9055	-4.7110	.0471	2.2552	.00	91.95	-.40	.105196	-.004130

TABLE 4 – (continued)

WAVE	36.0000	.015625	-0.09	-5.00	3.6932	-5.0032	3.1939	2.3205					
0	36.0000	.015625	-0.09	-5.00	3.6932	-5.0032			16.01	-60.89	1.68	-.000341	-.000282
1	36.0000	.015625	218.25	115.72	.0006	1.2055	3.7552	1.4006	16.42	-50.15	-.20	-.000357	-.000216
2	36.0000	.015625	422.56	247.50	.6952	.2060	3.3060	2.5050	15.06	-49.17	.00	-.000381	-.000105
3	36.0000	.015625	611.64	410.97	.4297	.4431	2.6273	3.6500	14.65	-22.20	.06	-.000431	-.000036
4	36.0000	.015625	706.05	642.34	.1020	.5346	1.6309	4.1932	.00	91.09	.06	.103965	.000384
WAVE	37.0000	.015625	-3.09	-9.51	5.9757	-1.9416	1.2200	3.7546					
0	37.0000	.015625	-3.09	-9.51	5.9757	-1.9416			11.02	-59.43	1.15	-.000549	-.000479
1	37.0000	.015625	212.04	117.57	3.3274	2.3059	2.0306	.7346	12.90	-50.29	-.00	-.000504	-.000364
2	37.0000	.015625	424.62	240.90	3.2612	2.2400	2.2347	1.6420	12.60	-40.99	.23	-.000513	-.000312
3	37.0000	.015625	613.19	412.04	2.5463	2.9432	2.0906	1.7672	13.73	-22.03	.20	-.000470	-.000234
4	37.0000	.015625	706.91	644.40	1.3957	3.3455	.9776	2.1791	.00	91.31	.34	.105781	.002943
WAVE	38.0000	.031250	3.09	-9.51	5.9757	1.9416	-1.2199	3.7546					
0	38.0000	.031250	3.09	-9.51	5.9757	1.9416			4.06	-58.73	.20	-.000040	-.000130
1	38.0000	.031250	216.59	120.14	5.4898	2.6755	1.2605	-.1102	7.90	-50.18	.22	-.000729	-.000110
2	38.0000	.031250	426.07	251.06	4.9536	3.4030	.7966	.6162	8.10	-40.75	.26	-.000704	-.000100
3	38.0000	.031250	616.70	416.57	4.1739	4.3319	.7419	.7774	10.30	-21.62	.49	-.000612	-.000065
4	38.0000	.031250	700.76	640.04	2.1793	5.1040	.3917	.9143	.00	91.75	.52	.109707	.004669
WAVE	39.0000	.062500	0.09	-5.00	3.6932	5.0032	-3.1939	2.3205					
0	39.0000	.062500	0.09	-5.00	3.6932	5.0032			0.91	-59.06	-.04	-.000670	.000540
1	39.0000	.062500	222.37	122.50	5.6094	2.0198	-.9056	-1.2257	9.99	-57.07	.40	-.000626	.000386
2	39.0000	.062500	433.94	255.47	4.0362	3.5594	-1.1050	-.5377	10.38	-40.40	.26	-.000621	.000332
3	39.0000	.062500	621.01	421.00	4.1614	4.4472	-.9353	-.6925	11.95	-21.12	.40	-.000544	.000247
4	39.0000	.062500	711.03	654.17	2.2300	5.2593	-.3767	-.0332	.00	92.29	.53	.114617	.004077
WAVE	40.0000	.031250	10.00	-.00	.0000	6.2832	-3.9478	.0000					
0	40.0000	.031250	10.00	-.00	.0000	6.2832			25.44	-60.31	-1.50	.000018	.000669
1	40.0000	.031250	227.18	123.84	3.9610	.3759	-3.1215	-1.9196	22.69	-57.41	.47	-.000096	.000543
2	40.0000	.031250	437.79	258.40	2.9602	2.1936	-2.9943	-2.0341	20.76	-40.26	.19	-.000177	.000460
3	40.0000	.031250	624.30	424.89	2.0959	2.0996	-2.6390	-2.4320	20.42	-20.76	.19	-.000191	.000332
4	40.0000	.031250	712.90	658.62	1.3452	3.2953	-1.2020	-3.0151	.00	92.74	.33	.110757	.003030
WAVE	41.0000	.007813	0.09	5.00	-3.6932	5.0032	-3.1939	-2.3205					
0	41.0000	.007813	0.09	5.00	-3.6932	5.0032			30.13	-62.01	-1.72	.000547	.000367
1	41.0000	.007813	220.97	123.26	-.9959	-1.4902	-3.0298	-1.6231	33.69	-57.00	.32	.000362	.000254
2	41.0000	.007813	438.71	259.49	-.7943	-.2902	-3.2426	-2.6262	30.66	-40.17	-.05	.000236	.000217
3	41.0000	.007813	625.04	426.25	-.5979	-.4365	-2.3310	-3.7052	25.45	-20.73	-.10	.000019	.000020
4	41.0000	.007813	713.52	660.07	-.1033	-.5000	-1.4406	-4.0326	.00	92.09	-.06	.120139	-.000425
WAVE	42.0000	.015625	3.09	9.51	-5.9757	1.9416	-1.2200	-3.7546					
0	42.0000	.015625	3.09	9.51	-5.9757	1.9416			53.04	-63.51	-1.17	.001202	.000041
1	42.0000	.015625	227.11	121.16	-3.5140	-2.5250	-3.0219	-.5100	44.67	-56.03	.00	.000028	.000614
2	42.0000	.015625	436.54	250.06	-3.3943	-2.4202	-2.2160	-1.0096	39.04	-40.37	-.32	.003619	.000510
3	42.0000	.015625	623.51	424.26	-2.3567	-3.4005	-1.5061	-2.6940	30.40	-20.91	-.26	.000225	.000355
4	42.0000	.015625	712.77	657.04	-1.2600	-3.7247	-1.0017	-2.9046	.00	92.66	-.30	.110422	-.002063
WAVE	43.0000	.031250	-3.09	9.51	-5.9757	-1.9416	1.2199	-3.7546					
0	43.0000	.031250	-3.09	9.51	-5.9757	-1.9416			67.20	-64.10	-.14	.001750	.000100
1	43.0000	.031250	222.36	118.57	-5.6677	-2.4702	-1.1525	.5796	54.73	-57.00	-.33	.001239	.000174
2	43.0000	.031250	432.20	254.91	-4.0422	-3.6614	-.5549	-.5405	40.37	-40.79	-.49	.000974	.000157
3	43.0000	.031250	620.54	419.77	-3.4189	-5.2365	-.5310	-.0174	36.13	-21.23	-.35	.000464	.000096
4	43.0000	.031250	711.09	652.92	-1.9032	-5.7654	-.3759	-.9709	.00	92.16	-.50	.114654	-.004399
WAVE	44.0000	.031250	-0.09	5.00	-3.6932	-5.0032	3.1939	-2.3205					
0	44.0000	.031250	-0.09	5.00	-3.6932	-5.0032			59.06	-63.77	.93	.001453	-.000794
1	44.0000	.031250	216.50	116.52	-5.6600	-1.5237	1.1525	1.2006	50.46	-57.45	-.53	.001061	-.000553
2	44.0000	.031250	427.44	251.19	-4.5370	-3.5507	1.1075	.7725	44.06	-49.20	-.46	.000020	-.000466
3	44.0000	.031250	617.07	414.43	-3.3770	-5.1326	.7409	1.0430	33.61	-21.50	-.33	.000359	-.000320
4	44.0000	.031250	709.03	646.99	-2.0105	-5.7370	.3369	1.0050	.00	91.56	-.59	.110151	-.004340

TABLE 4 – (continued)

WAVE	45.0000	.031250	-10.00	.00	-.0000	-6.2032	3.9478	-.0000					
0	45.0000	.031250	-10.00	.00	-.0000	-6.2032			34.60	-62.46	1.61	.000400	-.001119
1	45.0000	.031250	211.76	115.65	-3.4053	-.1949	3.0829	1.4232	31.47	-97.90	-.50	.000270	-.000006
2	45.0000	.031250	423.70	240.24	-2.9206	-2.1019	2.7042	1.9956	28.69	-49.65	-.25	.000154	-.000756
3	45.0000	.031250	614.32	410.14	-1.9500	-3.1146	1.0901	3.0399	22.42	-21.06	-.10	-.000100	-.000502
4	45.0000	.031250	707.32	642.17	-1.2710	-3.9360	1.1654	3.3302	.00	91.07	-.36	.106002	-.002675
WAVE	46.0000	.015625	-0.09	-5.00	3.6932	-5.0032	3.1939	2.3209					
0	46.0 00	.015625	-0.09	-5.00	3.6932	-5.0032			16.06	-60.77	1.67	-.000339	-.000211
1	46.0000	.015625	209.99	116.10	.0020	1.2611	3.7616	1.4076	16.40	-90.30	-.20	-.000355	-.000220
2	46.0000	.015625	422.01	247.20	.6751	.1091	3.3307	2.5651	15.93	-69.73	.00	-.000370	-.000197
3	46.0000	.015625	618.40	400.75	.3994	.4309	2.6423	3.6667	14.60	-21.91	.09	-.000430	-.000034
4	46.0000	.015625	706.74	640.50	.1856	.5174	1.6196	4.2111	.00	90.90	.09	.109200	.000307
WAVE	47.0000	.015625	-3.09	-4.51	5.9757	-1.9616	1.2200	3.7946					
0	47.0000	.015625	-3.09	-4.51	5.9757	-1.9616			11.76	-99.31	1.14	-.000992	-.000477
1	47.0000	.015625	211.70	118.01	3.3250	2.2094	2.0422	.7406	12.02	-58.52	-.01	-.000500	-.000362
2	47.0000	.015625	424.00	240.49	3.2656	2.2149	2.2563	1.6447	12.60	-49.95	.23	-.000917	-.000310
3	47.0000	.015625	615.01	410.62	2.5439	2.9412	2.1347	1.7562	13.77	-21.75	.20	-.000460	-.000232
4	47.0000	.015625	707.60	642.72	1.3002	3.3397	.9601	2.1096	.00	91.12	.34	.107003	.002907
WAVE	48.0000	.031250	3.09	-4.51	5.9757	1.9616	-1.2199	3.7946					
0	48.0000	.031250	3.09	-4.51	5.9757	1.9616			6.56	-90.62	.20	-.000652	-.000140
1	48.0000	.031250	216.33	120.57	5.4092	2.6601	1.2603	-.1064	7.39	-90.41	.22	-.000734	-.000126
2	48.0000	.031250	429.14	251.42	4.9674	3.6567	.0139	.6222	7.98	-49.30	.27	-.000709	-.000115
3	48.0000	.031250	618.53	414.34	4.1061	4.3230	.7977	.7053	10.36	-21.34	.50	-.000610	-.000069
4	48.0000	.031250	709.43	667.07	2.1590	5.0951	.3900	.9256	.00	91.57	.52	.110953	.004996
WAVE	49.0000	.062500	0.09	-5.00	3.6932	5.0032	-3.1939	2.3209					
0	49.0000	.062500	0.09	-5.00	3.6932	5.0032			8.70	-90.96	-.04	-.000679	.000567
1	49.0000	.062500	222.11	121.01	5.6967	2.0213	-.9767	-1.2210	9.70	-50.10	.40	-.000434	.000304
2	49.0000	.062500	434.22	295.02	6.0653	3.9396	-1.1720	-.5290	9.00	-49.02	.26	-.000630	.000332
3	49.0000	.062500	622.05	410.05	4.1043	4.6503	-.9266	-.6010	11.95	-20.02	.49	-.000544	.000245
4	49.0000	.062500	711.60	692.39	2.2150	5.2649	-.3663	-.0201	.00	92.11	.53	.119796	.004016
WAVE	50.0000	.031250	10.00	-.00	.0000	6.2032	-3.9478	.0000					
0	50.0000	.031250	10.00	-.00	.0000	6.2032			25.23	-60.19	-1.50	.000010	.000661
1	50.0000	.031250	226.93	124.27	3.5761	.3766	-3.0939	-1.9009	22.49	-57.65	.47	-.000105	.000532
2	50.0000	.031250	430.11	250.02	2.5070	2.1039	-2.9973	-2.0159	20.57	-40.00	.20	-.000105	.000466
3	50.0000	.031250	626.17	422.67	2.1096	2.9097	-2.6706	-2.4022	20.39	-20.46	.19	-.000192	.000327
4	50.0000	.031250	713.55	656.05	1.3601	3.2722	-1.2997	-3.0052	.00	92.56	.33	.119093	.003024

Figure 5 shows the tension in the upper cable segment for $0 \leq t \leq 20$ for Cases 1A to 1E, where C1 increases from 2.4×10 lb (1.07×10^2 N) to 2.4×10^5 lb (1.07×10^6 N). As would be expected, the figure shows that tension fluctuations increase with increasing values of C1. At the highest value of C1 = 2.4×10^5 lb (1.07×10^6 N), Figure 5 shows that the tension is zero at t = 0.25 sec (i.e., the cable in slack) and then jumps to a value of 89.47 lb (398.1 N) at t = 0.5 sec. This sudden jump in tension after a slack condition is often referred to as "snap loading." At the other extreme, the tension shows a peak-to-trough fluctuation of less than 2.5 lb (11.1 N) at the lowest value of C1 = 2.4×10 lb (1.07×10^2 N).

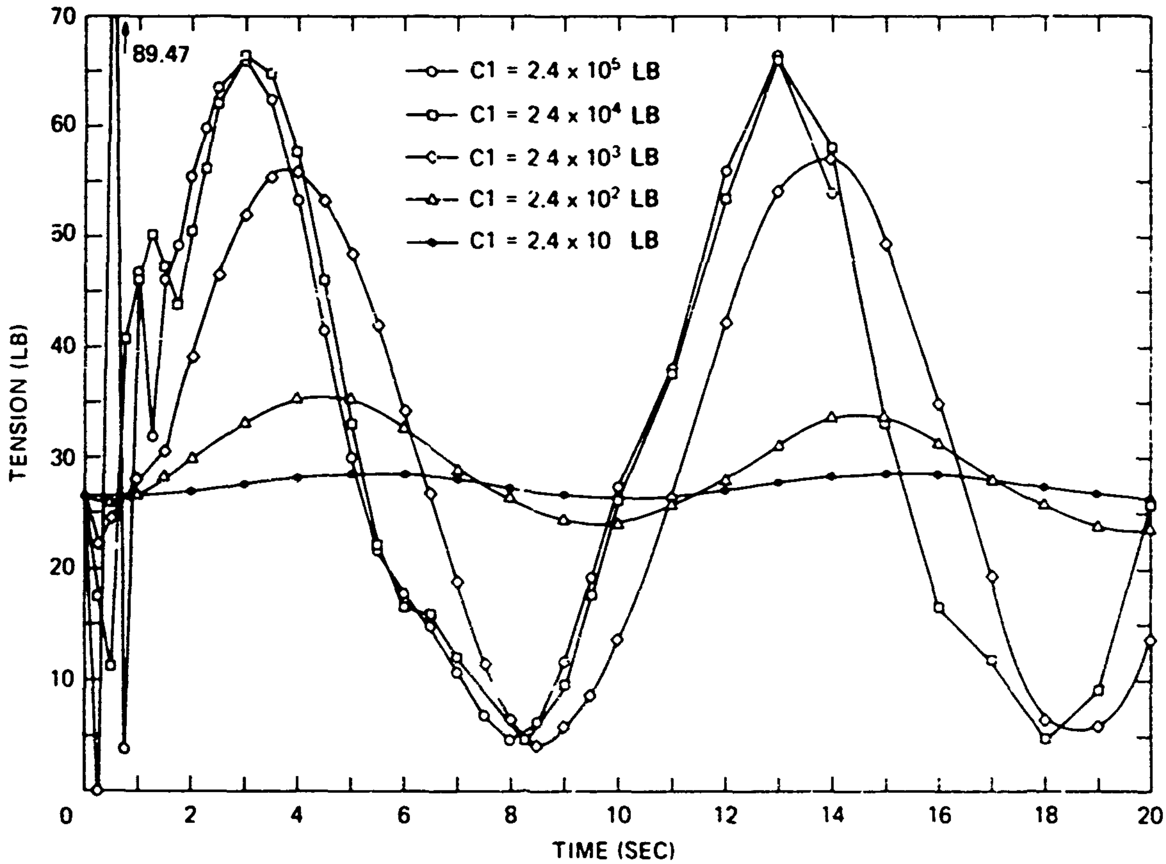


Figure 5 – Tension in Upper Cable Segment for Various Values of C1

Table 2 indicates that the computer execution time remains at approximately 60 sec for Cases 1A, 1B, and 1C for which C1 $\leq 2.4 \times 10^3$ lb (1.07×10^4 N). At higher values of C1, Cases 1D and 1E, execution time increases with increasing C1. Execution time also increases with decreasing values of C2, Case 1F. The reasons for these increases may be most conveniently explained by considering Equation (9) which shows that for a given value of

$(T - T_0)$. ϵ decreases with increasing values of C1 and decreasing values of C2. Small values of ϵ, in turn, mean that the x- and y-displacements must be calculated with greater precision, leading to smaller integration time steps.

PROBLEM 2 – UNIFORM CABLE REPRESENTED BY VARIOUS NUMBERS OF SEGMENTS

Problem: Solve Problem 1D with the single exception of representing the cable by the following number of nodes, NCAB-1: 1, 2, 4, 8, and 15. Consider the nodes to be equally spaced.

Solution: The data cards for this problem are listed in Table 5. Cards 1 and 4 to 12, which are identical to those for Problem 1D, are omitted. Also omitted are Cards 14 to 33 which are similar to those for Problem 1D with the exception that the number of entries depends on NCAB.

TABLE 5 – INPUT DATA FOR SAMPLE PROBLEM 2

	1	11	21	31	41	51	61	71
Card 2	bbb PROBLEM 2A, NCAB-1 = 1							
Card 3	bb1bb1bb2bb2							
Card 13	1000.							
Card 2	bbb PROBLEM 2B, NCAB-1 = 2							
Card 3	bb1bb1bb3bb2							
Card 13	500.	500.						
Card 2	bbb PROBLEM 2C, NCAB-1 = 4							
Card 3	bb1bb1bb5bb2							
Card 13	250.	250.	250.	250.				
Card 2	bbb PROBLEM 2D, NCAB-1 = 8							
Card 3	bb1bb1bb9bb2							
Card 13	125.	125.	125.	125.	125.	125.	125.	125.
Card 13	bbb							
Card 2	bbb PROBLEM 2E, NCAB-1 = 15							
Card 3	bb1bb1b16bb2							
Card 13	66 667	66.667	66 667	66.667	66.667	66.667	66.667	66.667
Card 13	66.667	66.667	66.667	66.667	66.667	66.667	66.667	

Figure 6 shows how the steady-state location of the lower weight varies with NCAB-1. The results are poor for NCAB-1 $\leq$ 2, good for NCAB-1 = 4, and converged for NCAB-1 $\geq$ 8.

Figure 7 shows the velocities $\dot{x}$ and $\dot{y}$ of the lower unit at t = 4 and 10 for various values of NCAB-1. The results suggest that a minimum of four nodes is required to obtain maximum

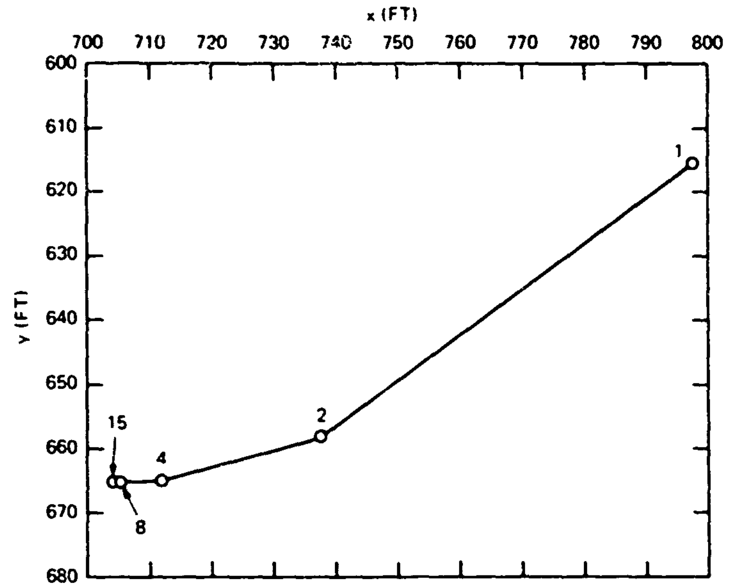


Figure 6 – Steady-State Location of Lower Weight for Various Numbers of Nodes

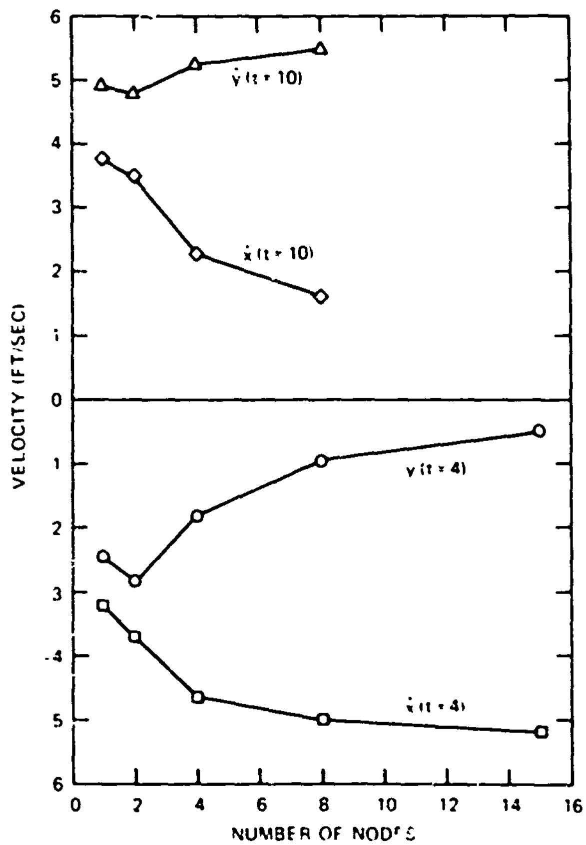


Figure 7 – Velocity of Lower Weight for Various Numbers of Nodes

velocities with accuracies to within 10-20 percent. The magnitudes of the computed velocities generally increase with increasing number of nodes.

Table 2 shows the manner in which the computer execution time ET increases with the number of nodes. The execution times are approximately proportional to NCAB squared

$$ET \alpha (NCAB)^2 \tag{56}$$

PROBLEM 3 – DEPLOYMENT OF SUSPENDED CABLE IN CIRCULATING WATER CHANNEL

Problem: Compute the deployment of an initially vertical cable, suspended in the DTNSRDC Circulating Water Channel, to its final steady-state configuration in the presence of channel flow speeds of 1, 2, and 4 knots (0.515, 1.03, 2.06 m/s). The fixed cable and lower body parameters are as follows:

Cable:

length	12 ft (3.66 m)
diameter	0.12 in. (0.305 cm)
normal drag coefficient	1.4
tangential drag coefficient	0.02
weight in fluid	0
mass	0.0002 slugs/ft (0.00957 kg/m)
reference tension	2 lb (8.9 N)
C_1	20 lb (89. N)
C_2	1.
internal damping coefficient	0.

Lower weight:

weight in fluid	2 lb (8.9 N)
drag area in x-direction	0.05 ft^2 (0.00465 m^2)
drag area in y-direction	0.05 ft^2 (0.00465 m^2)
virtual mass in x-direction	0.1 slugs (1.46 kg)
virtual mass in y-direction	0.1 slugs (1.46 kg)

Fluid density: 1.94 slugs/ft^3 (1000.6 kg/m^3)

Represent the cable by four equal segments, not including the fictitious cable segment below the lower weight. Take the total time interval to be 20 sec. For the initial interval of 1 sec, printout of the transient cable configuration is desired every 0.1 sec. For the final 19 sec, increase the printout interval to 0.2 sec. Let the system start from rest with the initial tension in each cable segment equal to 2 lb (8.9 N).

Solution: The data cards for this problem are listed in Table 6. The cards which are the same for all the cases are listed at the top of the table. The cards for the title and the current magnitude which differ for each case are listed at the bottom of the table.

TABLE 6 – INPUT DATA FOR SAMPLE PROBLEM 3

	1	11	21	31	41	51	61	71
Card 1	bb1							
Card 3	bb1bb1bb5bb2							
Card 4	0.1							
Card 5	0.							
Card 6	0.							
Card 7	0.							
Card 8	0.							
Card 9	0.1							
Card 10	0.							
Card 11	1.94	0.	0.	-15.	0.	1.0	1.0	0.
Card 12	1.	0.1	20.	0.2	-1.	0.	99999.	
Card 13	3.	3.	3.	3.				
Card 14	0.12	0.12	0.12	0.12				
Card 15	1.4	1.4	1.4	1.4				
Card 16	0.02	0.02	0.02	0.02				
Card 17	0.	0.	0.	0.				
Card 18	0.0002	0.0002	0.0002	0.0002				
Card 19	2.	2.	2.	2.				
Card 20	20.	20.	20.	20.				
Card 21	1.0	1.0	1.0	1.0				
Card 22	0.	0.	0.	0.				
Card 23	0.	0.	0.	2.				
Card 24	0.	0.	0.	0.05				
Card 25	0.	0.	0.	0.05				
Card 26	0.	0.	0.	0.1				
Card 27	0.	0	0.	0.1				
Card 28	0.	100.						
Card 30	0.	0.	0.	0.				
Card 31	2.	2.	2.	2.				
Card 32	0.	0.	0.	0.				
Card 33	0.	0.	0.	0.				

TABLE 6 – (continued)

	1 11 21 31 41 51 61 71
Card 2	bbb PROBLEM 3A, V = 1 KNOT
Card 29	1.0 1.0
Card 2	bbb PROBLEM 3B, V = 2 KNOTS
Card 29	2.0 2.0
Card 2	bbb PROBLEM 3C, V = 4 KNOTS
Card 29	4.0 4.0

Figures 8, 9, and 10 show the configuration of the cable nodes at various times during deployment for currents of 1, 2, and 4 knots (0.515, 1.03, 2.06 m/s), respectively. These figures show that approximately 8 sec are required to reach the steady-state configuration.

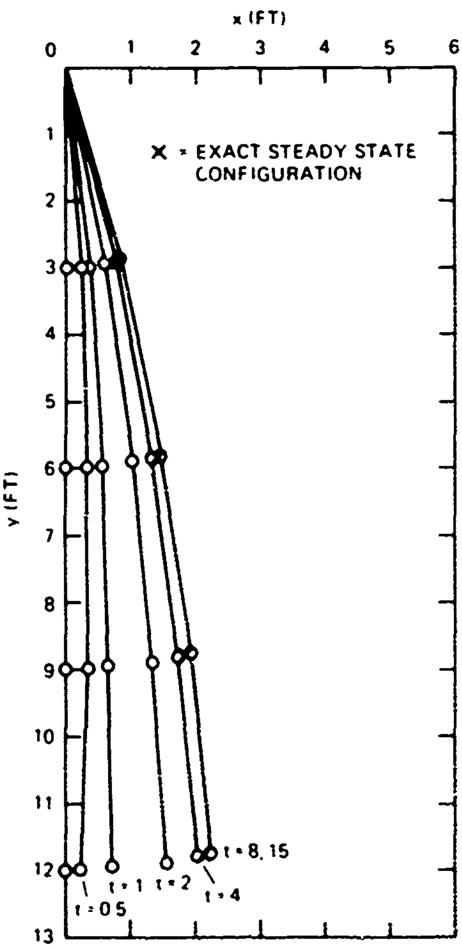


Figure 8 – Configuration of Nodes at Various Times during Deployment. C = 1 Knot

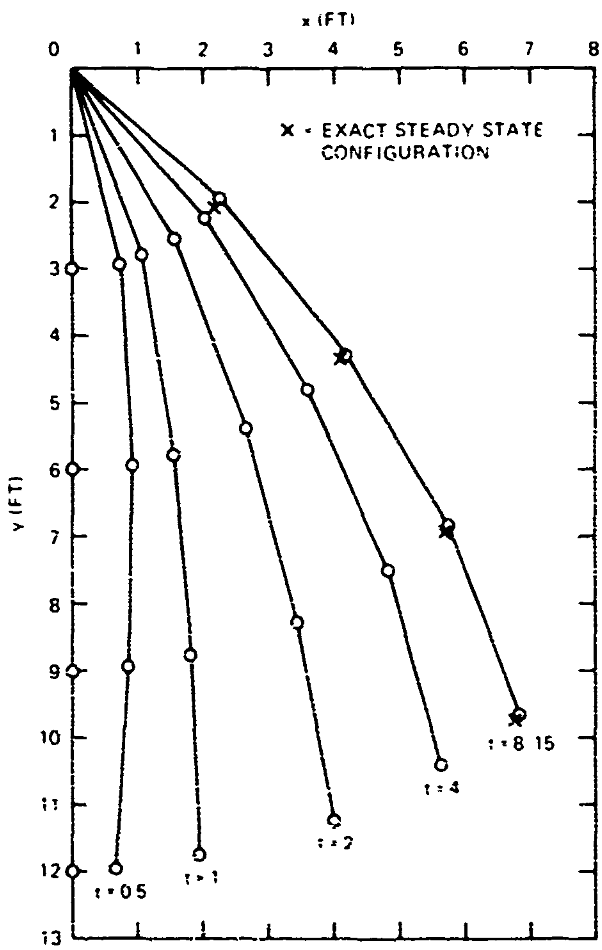


Figure 9 – Configuration of Nodes at Various Times during Deployment. C = 2 Knots

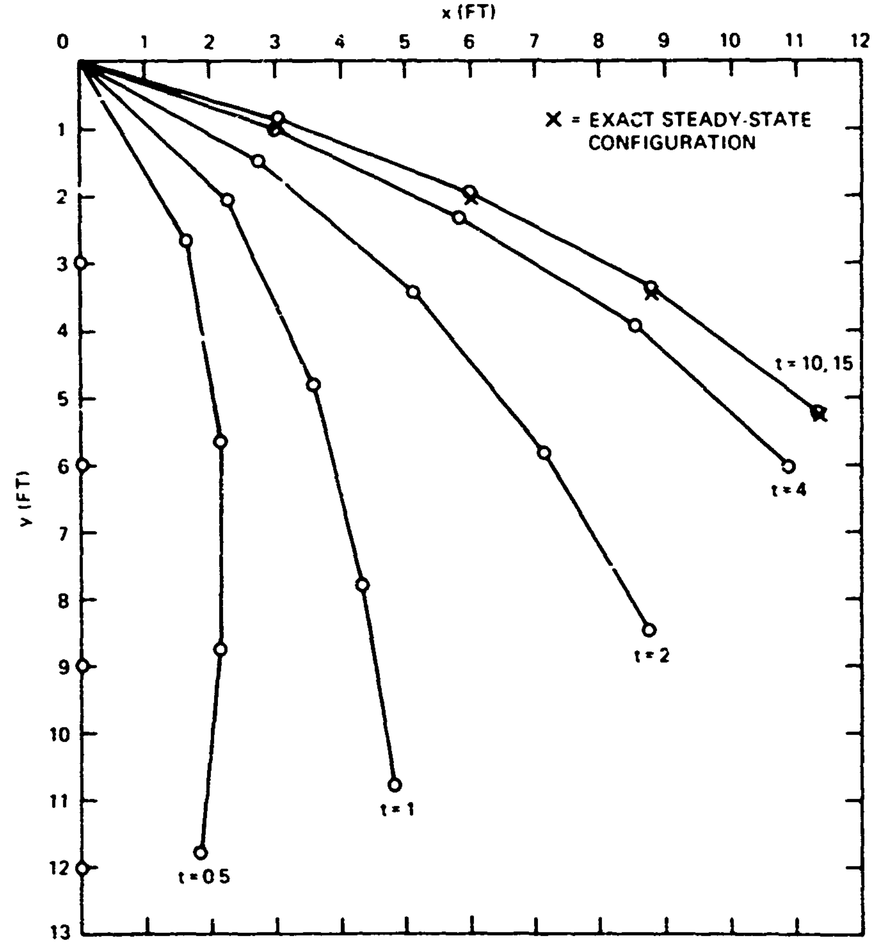


Figure 10 – Configuration of Nodes at Various Times during Deployment, C = 4 Knots

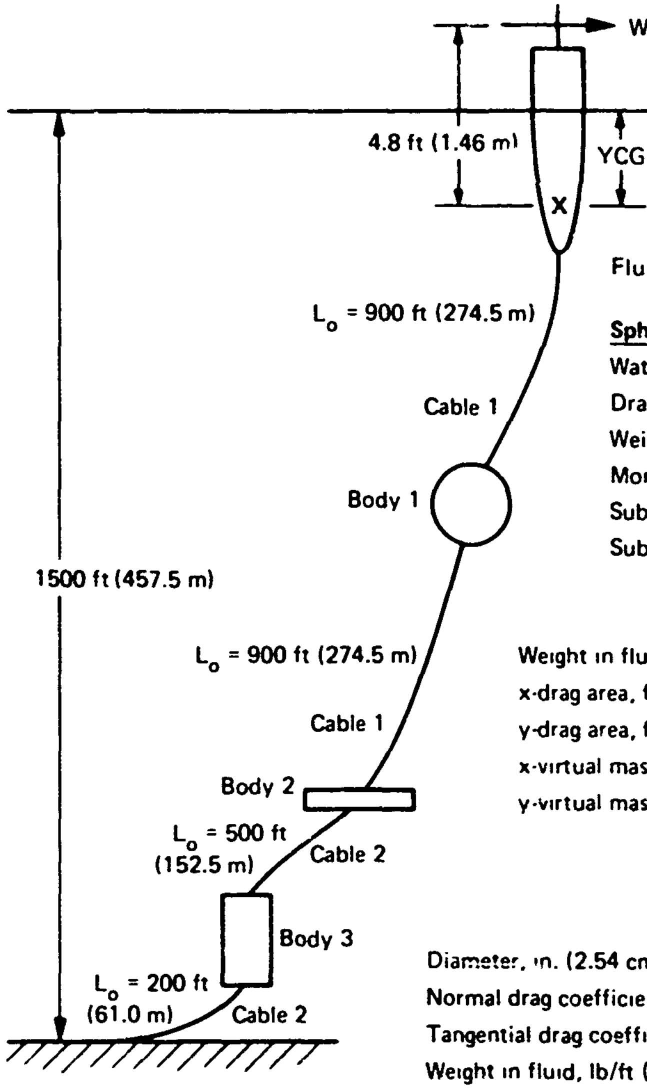
In all three cases, the final deployed configuration modeled by the four nodes was in close agreement with the exact configuration calculated by using the differential equations (1) to (5). It is of interest to note that because of its large inertia, the lower weight characteristically lags during the initial instants of deployment.

Table 2 shows that the computer execution time for a total of 20 sec of deployment time, which is well in excess of the 8 sec required to reach the steady-state configuration, is approximately 100 sec.

PROBLEM 4 – COMPLETE MOORED BUOY-CABLE-BODY SYSTEM

Problem: Compute the dynamic motions for the moored buoy-cable-body system, with parameters as shown in Table 7.

TABLE 7 – PARAMETERS FOR MOORED BUOY-CABLE-BODY SYSTEM



Fluid density = 1.99 slugs/ft^3 (1026 kg/m^3)

Spheroidal Surface Buoy

Waterplane radius	0.53 ft (0.162 m)
Draft	5.3 ft (1.62 m)
Weight in air	38 lb (169.1 N)
Moment of inertia	1.8 slug ft^2 (2.44 kg m^2)
Submerged x-drag area	3.15 ft^2 (0.293 m^2)
Submerged y-drag area	0.22 ft^2 (0.020 m^2)

	Body 1	Body 2	Body 3
Weight in fluid, lb (4.45 N)	-40.0	10.0	15.0
x-drag area, ft^2 (0.0929 m^2)	0.44	0.18	0.70
y-drag area, ft^2 (0.0929 m^2)	0.44	1.95	0.08
x-virtual mass, slugs (14.6 kg)	0.73	0.55	1.92
y-virtual mass, slugs (14.6 kg)	0.73	2.75	1.35

	Cable 1	Cable 2
Diameter, in. (2.54 cm)	0.15	0.25
Normal drag coefficient	1.4	1.4
Tangential drag coefficient	0.02	0.02
Weight in fluid, lb/ft (14.6 N/m)	0.04	0.02
Mass, slugs/ft (47.84 kg/m)	0.0015	0.0013
Reference tension, lb (4.45 N)	0.	100.
C_1 lb (4.45 N)	22,000.	1,600.
C_2	1.0	1.5
Internal damping coefficient, lb sec (4.45 N sec)	0.	0.

Current Profile:

Depth (ft) (0.305 m)	Current (knots) (0.515 m/s)
0.	2.50
500.	1.30
1000.	0.50
1500.	0.50

The upper body is a buoyancy bag, the middle body is a damping disk, and the lower body is an acoustic unit. Consider the following three cases:

Case A. Use the formulation contained in the program for a spheroidal buoy. Let the surface wave be composed of a single component with frequency = 0.1 cps, amplitude = 7.5 ft (2.29 m), and phase = 0 degrees.

Case B. Same as Case A except that the buoy is read in as a spar buoy, modeled by 11 cross-sectional areas as a function of depth from 0 to 5.3 ft (1.62 m).

Case C. Same as Case A except that the surface wave amplitudes are to be calculated by using the Pierson-Moskowitz sea spectrum for six components. Take the significant wave height as 15 ft (4.58 m), the range of frequencies from 0.04 to 0.28 cps, and the phase of the lowest frequency component equal to -60 deg.

For all three cases, model the cable by 4 nodes, with three of them corresponding to the three intermediate bodies and the extra node 200 ft of cable below the surface buoy. Compute the dynamic motions for 50 sec. For the initial 10 sec, print out the dynamic motions every 0.1 sec. For the final 40 sec, increase the printout interval to 0.5 sec. Let the system start from rest with the initial angle and tension of each segment equal to the steady-state values. Let the initial x-displacement of the buoy center of gravity be 7.5 ft (2.29 m).

Solution: The data cards for this problem are listed in Table 8. Again, cards which are the same for all the cases are listed at the top of the table. The cards for the title, surface buoy, and surface waves, which differ for each case, are listed at the bottom of the table.

Figure 11 shows the pitch angle ψ of the surface buoy for all three cases for $20 \leq t \leq 40$. Perhaps the principal feature is the comparison of the results for the same surface buoy treated as a spheroidal buoy and as a spar buoy. The figure shows that when the spheroidal buoy formulation was used, pitch results were about 1 to 2 deg higher than those obtained from the spar buoy formulation. This discrepancy is due to the difference in the added inertia terms for the two formulations (compare Equations (27), (28), (32) and Table 1).

The figure also shows that results for the single frequency cases 4A and 4B exhibit a periodic behavior with a period of 10 sec; the results for the multifrequency case 4C show a more random behavior.

Table 2 shows that the execution times for the single-frequency cases 4A and 4B were approximately 80 sec. This time was increased to 100 sec for Case 4C, where the program must calculate six components to obtain the surface wave.

TABLE 8 – INPUT DATA FOR SAMPLE PROBLEM 4

	1	11	21	31	41	51	61	71
Card 1	bb1							
Card 11	1.99	0.	4.5	-100.	3.15	1.0	1.0	0
Card 12	10.	0.1	50.	0.5	1.0	0.	99999.	
Card 13	200.	700.	900.	500.	200.			
Card 14	0.15	0.15	0.15	0.25	0.25			
Card 15	1.4	1.4	1.4	1.4	1.4			
Card 16	0.02	0.02	0.02	0.02	0.02			
Card 17	0.04	0.04	0.04	0.02	0.02			
Card 18	0.0015	0.0015	0.0015	0.0013	0.0013			
Card 19	0.	0.	0.	100.	100.			
Card 20	22000.	22000.	22000.	1600.	1600.			
Card 21	1.0	1.0	1.0	1.5	1.5			
Card 22	0.	0.	0.	0.	0.			
Card 23	0.	-40.	10.	15.	0.			
Card 24	0.	0.44	0.18	0.70	0.			
Card 25	0.	0.44	1.95	0.08	0.			
Card 26	0.	0.73	0.55	1.92	0.			
Card 27	0.	0.73	2.75	1.35	0.			
Card 28	0.	500.	1000.	1500.				
Card 29	2.50	1.30	0.50	0.50				
Card 30	9999.	0.	0.	0.	0.			
Card 31	0.	0.	0.	0.	0.			
Card 32	0.	0.	0.	0.	0.			
Card 33	0.	0.	0.	0.	0.			
Card 34	0.22	38.	-4.8	0.	1.6	3.7	1.8	
Card 35	7.5	0.	999.	0.	0.	0.		
Card 2	bbb PROBLEM 4A, SPHEROIDAL BUOY, SINGLE WAVE FREQUENCY							
Card 3	bb1bb1bb5bb4bb2							
Card 4	3500.							
Card 5	0.53							
Card 6	5.3							
Card 7	0.							
Card 8	7.5							
Card 9	0.1							
Card 10	0.							

TABLE 8 – (continued)

	1	11	21	31	41	51	[illegible]	71
Card 2	bbb PROBLEM 4B, SPAR BUOY, SINGLE WAVE FREQUENCY							
Card 3	b11bb1bb5bb4bb2							
Card 4	2700.							
Card 4								
Card 5	0.883	0.852	0.812	0.757	0.687	0.600	0.498	0.380
Card 5	0.247	0.097	0.					
Card 6	0.	1.0	1.5	2.0	2.5	3.0	3.5	4.0
Card 6	4.5	5.0	5.3					
Card 7	0.							
Card 7	0.							
Card 8	7.5							
Card 9	0.1							
Card 10	0.							
Card 2	bbb PROBLEM 4C, SPHEROIDAL BUOY, SIX WAVE FREQUENCIES							
Card 3	bb1bb6bb5bb4bb2							
Card 4	3500.							
Card 5	0.53							
Card 6	5.3							
Card 7	0.							
Card 8	1015.							
Card 9	0.04	0.28						
Card 10	-60.							

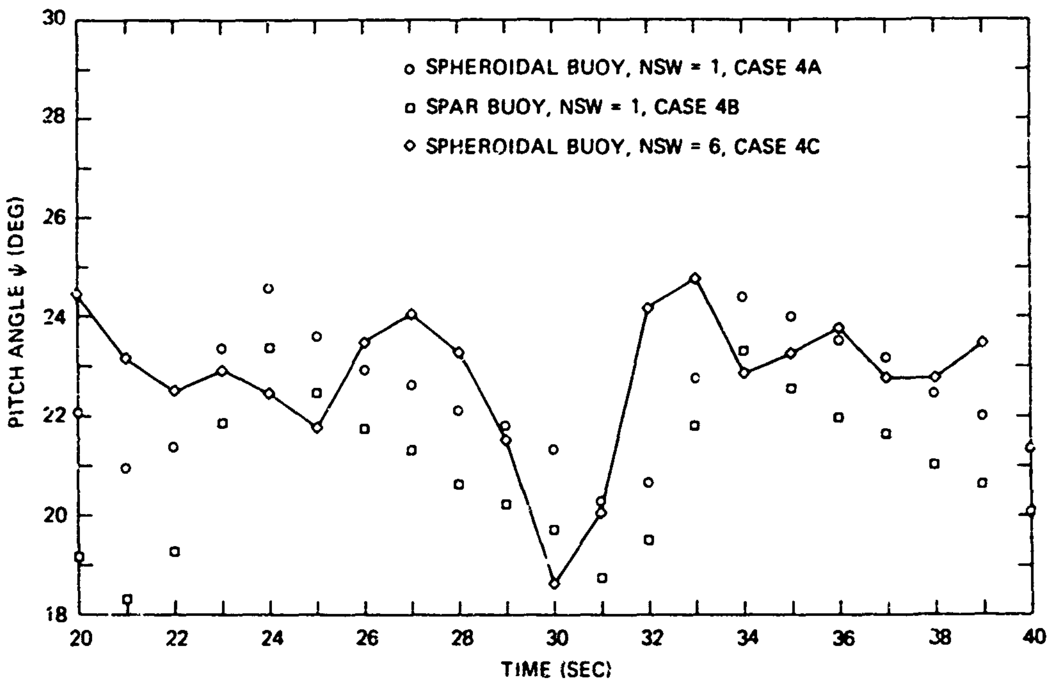


Figure 11 – Pitch of Surface Buoy

ACKNOWLEDGMENT

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APPENDIX

LISTING OF COMPUTER PROGRAM

```
PROGRAM CABUOY      74/74    OPT=0 ROUND=*/ TRACE           FTN 4.6+428          04/19/77  11.49.22        PAGE     1

      PROGRAM CABUOY(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)               CABUOY      2
      COMMON/MS1/DRAGN,DRAGT,WPUL,TRF,TC1,TEX1                            CABUOY      3
      COMMON/MD1/AXSM(20),AYSM(20),FISM(20),WKSM(20),SIG(20),WSM(20),     CABUOY      4
     1FISM(20),NSM                                                        CABUOY      5
      COMMON/MD3/TMIN,NCAB,NGE2,NDE1,DKUL,DKLL,TBYMX                      CORR        1
      COMMON/MD4/C1(50),C2(50),JINT(50),ORN(50),ORT(50),AMN(50),GM(50),   CABUOY      7
     1NTC(50),TREF(50),FLC(50)                                            CABUOY      8
      COMMON/MOSP/ASM(20),FRSM(20),NSM,MTRC                               CORR        2
      COMMON/MBD/RHO,PI,G,CCF1,FSM1,TMX,TXS,TYS,SUBM,RTY,RTX,RMY,YCG,     CABUOY     10
     1BIN,BG,MAS,COASX,COASY,XA,YA,XPA,YPA                                CABUOY     11
      COMMON/MDS3/XPPSI,ZETPP,SYPP,XSI,ZETI,SYI,XPSI,ZTPI,SYPI            CABUOY     12
      COMMON/CO5/WBO(50),COABX(50),COABY(50),XMBV(50),YMBV(50)            CABUOY     13
      COMMON/MDOK/XMB(50),YMB(50),TBM                                     CABUOY     14
      COMMON/MCU/YY(10),CCF(10),NCUR,FIRST,VCX                            CABUOY     15
      COMMON/DM1/XS,YS,XSP,YSP,XSPP,YSPP,X(51),Y(51),XP(51),              CABUOY     16
     1YP(51),XPP(51),YPP(51)                                              CABUOY     17
      COMMON/MIT/PHISL,XXL,YYL,TTL,VMX,VMN,BCYI,ITER,ICS,WBOT,ORGBTM,TIY  CORR        3
     1,SYISO                                                              CORR        4
      DIMENSION FSM(20),FIOSM(20),WLSM(20),DCI(50),CON(50),WC(50),        CABUOY     19
     1CDT(50),DM(50),CCK(10),FIOSM(20),XPI(51),YPI(51)                    CABUOY     20
      DIMENSION PHIO(51),Y0(106),PHIOS(102),TENIS(102),TENI(51),PHIV(51)  CABUOY     21
      DIMENSION TITLE(20)                                                 CORR        5
      EXTERNAL STAT,DYNA                                                  CABUOY     22
C     PRINT TABLE OF CONVERSION FROM ENGLISH UNITS TO METRIC UNITS        CORR        6
      WRITE(6,241)                                                        CORR        7
  241 FORMAT(1H1,/////,12X,                                               CORR        8
     1*CONVERSION FROM ENGLISH UNITS TO METRIC UNITS*//                   CORR        9
     225X,*ENGLISH*,3X,*METRIC*/25X,*1 INCH=*,3X,*2.540 CM*/              CORR       10
     325X,*1 FOOT=*,3X,*0.3048 METERS*/25X,*1 SQ FT=*,2X,*0.09290 SQ M*/  CORR       11
     425X,*1 CU FT=*,2X,*0.02831 CU M*/25X,*1 POUND=*,2X,*4.452 NEWTONS*  CORR       12
     5/25X,*1 SLUG=*,3X,*14.607 KGM*/25X,*1 SECOND=*,1X,*1 SECOND*/       CORR       13
     625X,*1 KNOT=*,3X,*0.5144M/SEC*)                                     CORR       14
      READ(5,1) NCASES                                                    CABUOY     23
    1 FORMAT(24I3)                                                        CABUOY     24
C     READ IN DATA                                                        CABUOY     25
      READ(5,301) TITLE                                                   CORR       15
  301 FORMAT(20A4)                                                        CORR       16
      READ(5,1) NSM,NSM,NCAB,NCUR,ITER,MTRC                               CORR       17
      NBD=NCAB-1                                                          CABUOY     27
      READ(5,2) (FSM(K),K=1,NSM)                                          CABUOY     28
    2 FORMAT(8F10.4)                                                      CABUOY     29
    3 FORMAT(8F10.2)                                                      CABUOY     30
    4 FORMAT(8F10.6)                                                      CABUOY     31
    5 FORMAT(8F10.0)                                                      CABUOY     32
      READ(5,2) (AXSM(K),K=1,NSM)                                         CABUOY     33
      READ(5,2) (AYSM(K),K=1,NSM)                                         CABUOY     34
      READ(5,2) (FIOSM(K),K=1,NSM)                                        CABUOY     35
      READ(5,2) (ASM(K),K=1,NSM)                                          CABUOY     36
      READ(5,2) (FRSM(K), K=1,NSM)                                        CABUOY     37
      READ(5,2) (FIOSM(K),K=1,NSM)                                        CABUOY     38
      READ(5,2) RHO,SUBM,TMX,TIY,COASX,AMG,AFAC,TMIN                      CABUOY     39
      READ(5,2) TANV1,DT1,TOTT,DT2,DIR,TBM,TBYMX                          CORR       18
      READ(5,3) (FLC(K),K=1,NCAB)                                         CABUOY     41
      READ(5,2) (DCI(K),K=1,NCAB)                                         CABUOY     42
      READ(5,2) (DM(K),K=1,NCAB)                                          CABUOY     43
      READ(5,2) (CDT(K),K=1,NCAB)                                         CABUOY     44
      READ(5,2) (WC(K),K=1,NCAB)                                          CABUOY     45
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          READ(5,4)  (CM(K),K=1,NCAB)                                   CABUOY     46
          READ(5,3)  (TREF(K),K=1,NCAB)                                 CABUOY     47
          READ(5,5)  (C1(K),K=1,NCAB)                                   CABUOY     48
          READ(5,2)  (C2(K),K=1,NCAB)                                   CABUOY     49
          READ(5,2)  (CINT(K),K=1,NCAB)                                 CABUOY     50
          READ(5,2)  (WBD(K),K=1,NCAB)                                  CABUOY     51
          READ(5,2)  (CDABX(K),K=1,NCAB)                                CABUOY     52
          READ(5,2)  (CDABY(K),K=1,NCAB)                                CABUOY     53
          READ(5,2)  (XMBV(K),K=1,NCAB)                                 CABUOY     54
          READ(5,2)  (YMBV(K),K=1,NCAB)                                 CABUOY     55
          READ(5,3)  (YY(I),I=1,NCUR)                                   CABUOY     56
          READ(5,2)  (PHIO(I),I=1,NCAB)                                 CABUOY     57
          READ(5,3)  (TENI(I),I=1,NCAB)                                 CABUOY     58
          READ(5,2)  (XPI(I),I=1,NCAB)                                  CABUOY     59
          READ(5,2)  (YPI(I),I=1,NCAB)                                  CABUOY     60
          DIRP=DIR                                                      CORR       19
          DO 1000 MC=1,NCASES                                           CABUOY     61
          DIR=DIRP                                                      CORR       20
          READ(5,3)  (CCK(I),I=1,NCUR)                                  CABUOY     62
          IF(MTRC.LE.0) GO TO 221                                       CORR       21
C     CONVERT METRIC INPUT TO ENGLISH UNITS                             CORR       22
          DO 222 I=1,NSM                                                CORR       23
          AXSM(I)=3.281*AXSM(I)                                         CORR       24
          IF(FSM(1).GE.2000..AND.FSM(1).LT.3000.) AXSM(I)=3.281*AXSM(I) CORR       25
      222 AYSM(I)=3.281*AYSM(I)                                         CORR       26
          IF(ASM(1).LE.1000.) GO TO 224                                 CORR       27
          ASM(1)=1000.+3.281*(ASM(1)-1000.)                             CORR       28
          GO TO 226                                                     CORR       29
      224 CONTINUE                                                      CORR       30
          DO 225 I=1,NSM                                                CORR       31
      225 ASM(1)=3.281*ASM(I)                                           CORR       32
      226 RHO=0.0019388*RHO                                             CORR       33
          SUBM=3.281*SUBM$TWX=TWX/4.452$TIY=TIY/4.452                   CORR       34
          GDASX=3.281*3.281*GDASX$TMIN=TMIN/4.452$TBH=TBH/4.452         CORR       35
          TBYMX=TBYMX/4.452                                             CORR       36
          DO 227 K=1,NCAB                                               CORR       37
          FLC(K)=3.281*FLC(K)$DCI(K)=0.3937*DCI(K)$WC(K)=0.06846*WC(K)  CORR       38
          CM(K)=0.02047*CM(K)$TREF(K)=TREF(K)/4.452$C1(K)=C1(K)/4.452   CORR       39
          CINT(K)=CINT(K)/4.452$WBD(K)=WBD(K)/4.452                     CORR       40
          CDABX(K)=3.281*3.281*CDABX(K)$CDABY(K)=3.281*3.281*CDABY(K)   CORR       41
          XMBV(K)=0.068467*XMBV(K)$YMBV(K)=0.068467*YMBV(K)             CORR       42
          TENI(K)=TENI(K)/4.452$XPI(K)=3.281*XPI(K)                     CORR       43
      227 YPI(K)=3.281*YPI(K)                                           CORR       44
          DO 228 I=1,NCUR                                               CORR       45
          YY(I)=3.281*YY(I)                                             CORR       46
      228 CCK(I)=3.281*CCK(I)/1.6878                                    CORR       47
      221 CONTINUE                                                      CORR       48
          IF(C1(NCAB).GT.0.0001) GO TO 115                              CORR       49
          FLC(NCAB)=2.*FLC(NCAB-1)$DCI(NCAB)=0.$CON(NCAB)=0.            CORR       50
          DCI(NCAB)=0.$WC(NCAB)=0.$CM(NCAB)=0.$TREF(NCAB)=0.$C1(NCAB)=0.001 CORR   51
          C2(NCAB)=1.$CINT(NCAB)=0.                                     CORR       52
      115 CONTINUE                                                      CORR       53
          FDISM=FIDSM(1)                                                CORR       54
          FSM1=FSM(1)                                                   CABUOY     64
          PI=3.14159265$G=32.2                                          CABUOY     65
          XS1=0.                                                        CABUOY     66
          DKUL=2.2/1.12                                                 CABUOY     67
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            DKLL=1./3.6                                                CABUOY    68
            DO 151 I=1,NCAB                                            CABUOY    69
            XMB(I)=XMBV(I)$YMB(I)=YMBV(I)                              CABUOY    70
        151 CONTINUE                                                   CABUOY    71
            IF(ASW(1).LE.1000.) GO TO 88                               CABUOY    72
            DO 89 I=1,NSW                                              CABUOY    73
            FNSW=NSW                                                   CABUOY    74
            FI=I-1                                                     CABUOY    75
         89 FIDSW(I)=FIDSW+(360.*FI)/FNSW                              CORR      55
            CALL SPECT                                                 CABUOY    77
         88 CONTINUE                                                   CABUOY    78
            DO 51 I=1,NSW                                              CABUOY    79
            SIG(I)=2.*PI*FRSW(I)                                       CABUOY    80
            WLSW(I)=2.*PI*G/(SIG(I)*SIG(I))                            CABUOY    81
            WKSW(I)=2.*PI/WLSW(I)                                      CABUOY    82
         51 FISW(I)=FIDSW(I)*PI/180.                                   CABUOY    83
            IF((FSM1.LE.1000.).OR.(FSM1.GE.2000.)) GO TO 91            CABUOY    84
            NSM=NSW                                                    CORR      56
            DO 90 I=1,NSM                                              CABUOY    85
            FSM(I)=FRSW(I)$FIDSM(I)=FIDSW(I)                           CABUOY    86
            AXSM(I)=ASW(I)$AYSM(I)=ASW(I)                              CABUOY    87
         90 CONTINUE                                                   CABUOY    88
         91 CONTINUE                                                   CABUOY    89
      C     PRINT DATA                                                 CABUOY    90
            WRITE(6,302) TITLE                                         CORR      57
        302 FORMAT(1H1,10X,20A4)                                       CORR      58
            WRITE(6,6)                                                 CORR      59
          6 FORMAT(/10X,                                               CORR      60
           155HLISTING OF ENVIRONMENTAL AND CABLE-BUOY CHARACTERISTICS)  CABUOY  93
            WRITE(6,7)                                                 CABUOY    94
          7 FORMAT(/5X,16HOCEAN CONDITIONS)                            CABUOY    95
            WRITE(6,8)                                                 CABUOY    96
          8 FORMAT(/1X,13HSURFACE WAVE-,5X,9HFREQ(CPS),1X,8HAMPL(FT),2X,  CABUOY 97
           18HPHASE(D),3X,6HWL(FT),2X,8HWK(1/FT))                      CABUOY    98
            DO 31 I=1,NSW                                              CABUOY    99
         31 WRITE(6,9) FRSW(I),ASW(I),FIDSW(I),WLSW(I),WKSW(I)         CABUOY   100
          9 FORMAT(17X,4F10.2,F10.4)                                   CABUOY   101
            WRITE(6,10)                                                CABUOY   102
         10 FORMAT(/1X,15HCURRENT PROFILE,5X,9HDEPTH(FT),2X,8HCURR(KT))  CABUOY 103
            DO 32 I=1,NCUR                                             CABUOY   104
         32 WRITE(6,11) YY(I),CCK(I)                                   CABUOY   105
         11 FORMAT(20X,2F10.2)                                         CABUOY   106
            WRITE(6,12) RHO                                            CABUOY   107
         12 FORMAT(/1X,14HFLUID DENSITY=,F10.4,1X,7HSL/CUFT)           CABUOY   108
            WRITE(6,13)                                                CABUOY   109
         13 FORMAT(//5X,15HSURFACE MOTION-,9HFREQ(CPS),3X,7HX-A(FT),3X,  CABUOY 110
           17HY-A(FT),1X,10HPHASE(DEG))                                CABUOY   111
            DO 33 I=1,NSM                                              CABUOY   112
         33 WRITE(6,14) FSM(I),AXSM(I),AYSM(I),FIDSM(I)                CABUOY   113
         14 FORMAT(20X,4F10.4)                                         CABUOY   114
            WRITE(6,15)                                                CABUOY   115
         15 FORMAT(//1X,29HGENERAL CABLE CHARACTERISTICS)              CABUOY   116
            WRITE(6,16)                                                CABUOY   117
         16 FORMAT(/2X,8HAM COEFF,2X,8HAREA FAC,2X,9HT MIN(LB))        CABUOY   118
            WRITE(6,17) AMC,AFAC,TMIN                                  CABUOY   119
         17 FORMAT(2F10.4,F10.2)                                       CABUOY   120
            WRITE(6,18)                                                CABUOY   121
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   16 FORMAT(//5X,16HCABLE PROPERTIES,72X,15HBODY PROPERTIES)            CABUOY   122
      WRITE(6,19)                                                        CABUOY   123
   19 FORMAT(1X,3HNUM,3X,7HLEN(FT),2X,8HDIAM(IN),2X,3HCON,5X,3HCDT,3X,  CABUOY   124
     17HW(LB/F),1X,7HM(SL/F),1X,9HT REF(LB),3X,6HC1(LB),1X,              CABUOY   125
     21X,6HEXP C2,2X,8HCINT(LB),1X,8HCDAX(F2),1X,8HCDAY(F2),1X,          CABUOY   126
     36HWT(LB),1X,7HXVM(SL),1X,7HYVM(SL))                                CABUOY   127
      DO 34 I=1,NCAB                                                     CABUOY   128
      WRITE(6,20) I,FLC(I),DCI(I),CON(I),CDT(I),WC(I),CM(I),TREF(I),     CABUOY   129
     1C1(I),C2(I),CINT(I),CDABX(I),CDABY(I),WBO(I),XMBV(I),YMBV(I)       CABUOY   130
   34 CONTINUE                                                           CABUOY   131
   20 FORMAT(1X,I3,F10.2,4F8.4,F8.6,F10.2,F10.0,F8.4,                    CABUOY   132
     1F8.4,2X,3F6.3,2F8.4)                                               CABUOY   133
      WRITE(6,55) TBH                                                    CORR      61
   55 FORMAT(/1X,17HX-LOAD ON BOT WT=,F12.4,1X,2HLB)                     CORR      62
      WRITE(6,59)                                                        CORR      63
   59 FORMAT(//1X,28HSURFACE BUOY CHARACTERISTICS)                       CORR      64
      WRITE(6,52)                                                        CORR      65
   52 FORMAT(/6X,8HSUBM(FT),2X,11HWIND LO(LB),2X,10HCDAX(FTSQ),2X,       CORR      66
     111HMAX TEN(LB))                                                    CORR      67
      WRITE(6,53) SUBM,TWX,CDASX,TBYMX                                   CORR      68
   53 FORMAT(4F12.4)                                                     CORR      69
C     SET CONSTANTS AND CONVERT DATA                                     CABUOY   134
      EPSTA=0.00001$EPOYM=0.0001$EPR=0.0000'                             CORR      70
      RAD=180./PI                                                        CABUOY   136
      DELTA=0.00000001                                                   CABUOY   137
      DO 41 I=1,NSM                                                      CABUOY   138
      WSM(I)=2.*PI*FSM(I)                                                CABUOY   139
      FISM(I)=FISM(I)*PI/180.                                            CABUOY   140
   41 CONTINUE                                                           CABUOY   141
      DO 42 I=1,NCUR                                                     CABUOY   142
   42 CCF(I)=CCK(I)*1.6878                                               CABUOY   143
      WBOT=WBO(NBO)                                                      CABUOY   144
      VCX=0.                                                             CABUOY   145
      ICS=1                                                              CABUOY   146
      SYISO=0.                                                           CORR      71
      IF(ITER.LE.0) GO TO 93                                             CABUOY   147
C     PERFORM INITIAL CALCULATIONS FOR ITERATION CASES                   CORR      72
      DIR=1.0                                                            CORR      73
   95 BCYI=0.                                                            CABUOY   153
      DO 96 I=1,NCAB                                                     CABUOY   154
   96 BCYI=BCYI+FLC(I)*WC(I)+WBO(I)                                      CABUOY   155
      TOT =0.                                                            CABUOY   156
      DO 198 I=1,NCAB                                                    CORR      74
  198 TOTL=TOTL+1.1*FLC(I)                                               CORR      75
      VMX=-1000.$VMN=1000.                                               CORR      76
      DO 94 I=1,NCUR                                                     CABUOY   159
      IF(CCF(I).GT.VMX) VMX=CCF(I)                                       CABUOY   160
      IF(CCF(I).LT.VMN) VMN=CCF(I)                                       CABUOY   161
      IF(YY(I).GT.TOTL) GO TO 102                                        CORR      77
   94 CONTINUE                                                           CABUOY   163
  102 IF(VMX.LT.0.) GO TO 103                                            CORR      78
      VMX=1.05*VMX                                                       CORR      79
      VMN=0.95*VMN                                                       CORR      80
      GO TO 93                                                           CORR      81
  103 VMX=0.95*VMX                                                       CORR      82
      VMN=1.05*VMN                                                       CORR      83
   93 CALL ITERA                                                         CABUOY   164
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C     CALCULATE STEADY-STATE VARIABLES                                       CABUOY    165
      FIRST=-1.                                                              CABUOY    166
      CALL CUR(SUBM,CU)                                                      CABUOY    167
      CCF1=CU                                                                CABUOY    168
      TDX=0.5*RHO*CDASX*CCF1*ABS(CCF1)                                       CABUOY    169
      TIX=TDX+TWX                                                            CABUOY    170
      IF(DIR.LT.0.) TIX=0.5*RHO*ABS(CDABX(NBD))*CCF1*ABS(CCF1)+TBH           CORR       84
      IF(DIR.LT.0.) TIY=WBD(NCAB-1)                                          CABUOY    172
      TI=SQRT(TIX*TIX+TIY*TIY)                                               CABUOY    173
   63 PHIS=ATAN2(TIX,-TIY)                                                   CABUOY    174
      TEN=TI                                                                 CABUOY    175
      PHISD=PHIS*RAD                                                         CABUOY    176
      TYS=-TIY$TXS=-TIX                                                      CABUOY    177
      IF(FSM1.LE.2000.) GO TO 98                                             CABUOY    178
      IF(DIR.LT.0.) GO TO 96                                                 CABUOY    179
      CALL BUOY                                                              CABUOY    180
      GO TO 99                                                               CABUOY    181
   98 CONTINUE                                                               CABUOY    182
      XA=0.$YA=SUBM$XPA=0.$YPA=0.                                            CABUOY    183
      DO 44 I=1,NSM                                                          CABUOY    184
      XA=XA+AXSM(I)*COS(FISM(I))                                             CABUOY    185
      YA=YA-AYSM(I)*SIN(FISM(I))                                             CABUOY    186
      XPA=XPA+WSM(I)*AXSM(I)*SIN(FISM(I))                                    CORR       85
      YPA=YPA+WSM(I)*AYSM(I)*COS(FISM(I))                                    CORR       86
   44 CONTINUE                                                               CABUOY    189
   99 CONTINUE                                                               CABUOY    190
      XC=XA$YC=YA$SR=0.$SE=0.                                                CORR       87
      IF(ITER.GE.1) GO TO 204                                                CABUOY    191
      WRITE(6,116)                                                           CABUOY    192
  116 FORMAT(/1X,30HINITIAL VALUES AT TOP OF CABLE)                          CABUOY    193
      WRITE(6,117) XA,YA,XPA,YPA                                             CABUOY    194
  117 FORMAT(1X,3HXA=,F10.4,5X,3HYA=,F10.4,5X,4HXVA=,F10.4,5X,4HYVA=,        CABUOY    195
     1F10.4)                                                                 CABUOY    196
   45 WRITE(6,65) NC                                                         CABUOY    197
   65 FORMAT(1H1,5X,10HRUN NUMBER,I3)                                        CABUOY    198
      WRITE(6,66)                                                            CABUOY    200
   66 FORMAT(/10X,26HSTEADY-STATE CONFIGURATION)                             CABUOY    201
      WRITE(6,68) TIX,TIY,DIR                                                CABUOY    202
   68 FORMAT(/1X,4HTIX=,F10.2,5X,4HTIY=,F10.2,5X,10HDIRECTION=,F10.2)        CABUOY    203
      WRITE(6,67)                                                            CABUOY    204
   67 FORMAT(/1X,4HNODE,1X,9HS REF(FT),                                      CABUOY    205
     11X,9HS STR(FT),3X,5HX(FT),5X,5HY(FT),3X,7HTEN(LB),3X,9HPHIS(DEG))      CABUOY    206
      JS=0                                                                   CABUOY    207
      WRITE(6,69) JS,SR,SE,XC,YC,TEN,PHISD                                   CABUOY    208
   69 FORMAT(I4,1X,6F10.2)                                                   CABUOY    209
  204 IN=1                                                                   CABUOY    210
      ILST=NCAB                                                              CABUOY    211
      IF(DIR.LT.0.) ILST=NBD                                                 CABUOY    212
C     COMPUTE STEADY-STATE CONFIGURATION                                     CABUOY    213
      DO 71 I=IN,ILST                                                        CABUOY    214
      IC=I                                                                   CABUOY    215
      IF(DIR.LT.0.) IC=NCAB-I                                                CABUOY    216
      START=0.                                                               CABUOY    217
      DRAGN=0.5*RHO*(DCI(IC)/12.)*CON(IC)                                    CABUOY    218
      DRAGT=0.5*RHO*(DCI(IC)/12.)*COT(IC)                                    CABUOY    219
      WPUL=WC(IC)                                                            CABUOY    220
      TRF=TREF(IC)                                                           CABUOY    221
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PROGRAM CABUOY      74/74    OPT=0 ROUND=*/ TRACE          FTN 4.6+428        04/19/77  11.49.22        PAGE     6

            TC1=C1(IC)                                                          CABUOY    222
            TEX1=1./C2(IC)                                                      CABUOY    223
            SPA=FLC(IC)/2.                                                      CABUOY    224
            DO 81 II=1,2                                                        CABUOY    225
            Y0(1)=TEN                                                           CABUOY    226
            Y0(2)=PHIS                                                          CABUOY    227
            Y0(3)=XC                                                            CABUOY    228
            Y0(4)=YC                                                            CABUOY    229
            Y0(5)=SE                                                            CABUOY    230
            CALL KUTMER(5,SR,Y0,EPSTA,SPA,START,HCX,EPR,STAT)                   CORR       88
            FIRST=1.                                                            CABUOY    232
            TEN=Y0(1)$PHIS=Y0(2)$XC=Y0(3)$YC=Y0(4)$SE=Y0(5)                     CABUOY    233
            PHISD=Y0(2)*RAD                                                     CABUOY    234
            IF(ITER.GE.1) GO TO 205                                             CABUOY    235
            WRITE(6,69) IC,SR,SE,XC,YC,TEN,PHISD                                CABUOY    236
        205 IF(II-1) 81,72,81                                                   CABUOY    237
         72 IC=IC                                                               CABUOY    238
            TENIS(IU)=TEN                                                       CABUOY    239
            PHIDS(IU)=PHISD                                                     CABUOY    240
         81 CONTINUE                                                            CABUOY    241
      C   COMPUTE TENSION AND ANGLE AT BODY                                     CABUOY    242
            CALL CUR(YC,CB)                                                     CABUOY    243
            IB=IC                                                               CABUOY    244
            IF(DIR.LT.0.) IB=IC-1                                               CABUOY    245
            IF(IB.LE.0) GO TO 144                                               CABUOY    246
            FBX=0.5*RHO*ABS(CDABX(IB))*CB*ABS(CB)                               CABUOY    247
            IF(IB.EQ.NBD) FBX=FBX+TBH                                           CABUOY    248
            IF(IB.EQ.NBD) DRGBTH=FBX                                            CABUOY    249
        143 FBY=WBU(IB)                                                         CABUOY    250
            TB1=SIN(PHIS)*TEN+FBX                                               CABUOY    251
            TB2=-COS(PHIS)*TEN+FBY                                              CABUOY    252
            IF(ABS(TB2).LT.DELTA) TB2=DELTA                                     CABUOY    253
            TEN=SQRT(TB1*TB1+TB2*TB2)                                           CABUOY    254
            PHIS=ATAN2(TB1,-TB2)                                                CABUOY    255
            PHISD=PHIS*RAD                                                      CABUOY    256
            IF(IC.EQ.NBD) XXLBT=XC                                              CORR       89
            I.(IC.EQ.NBD) YYLBT=YC                                              CORR       90
            IF(ITER.GE.1) GO TO 71                                              CABUOY    257
        144 WRITE(6,69) IB,SR,SE,XC,YC,TEN,PHISD                                CABUOY    258
         71 CONTINUE                                                            CABUOY    259
            THORX=-TEN*SIN(PHIS)                                                CABUOY    260
            TVERT=+TEN*COS(PHIS)                                                CABUOY    261
            IF(ITER.GE.1) GO TO 207                                             CABUOY    262
            WRITE(6,73)                                                         CABUOY    263
         73 FORMAT(/)                                                           CABUOY    264
            WRITE(6,75) THORX                                                   CABUOY    265
            WRITE(6,76) TVERT                                                   CABUOY    266
         75 FORMAT(1X,23HX-COMPONENT OF TENSION=,F10.2,1X,2HLB)                 CABUOY    267
         76 FORMAT(1X,23HY-COMPONENT OF TENSION=,F10.2,1X,2HLB)                 CABUOY    268
            IF(ITER.LE.0) GO TO 211                                             CORR       91
      C   DEFINE END CONDITIONS FOR TRANSMITTAL TO SUBROUTINE ITERA             CABUOY    269
        207 PHISL=PHIS                                                          CABUOY    270
            XXL=XC                                                              CABUOY    271
            YYL=YC                                                              CABUOY    272
            TTL=TEN                                                             CABUOY    273
            IF(ICS.EQ.1) WRITE(6,202)                                           CORR       92
        202 FORMAT(1H1,2X,3HITN,5X,4HVGXK,8X,4HTIXX,                            CORR       93
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      18X,4HTIYY,8X,4HTENB,8X,4HPHIB,8X,                          CORR        94
      14HTBXX,8X,4HTBYY,8X,4HXXBB,8X,4HYYBB-                      CORR        95
      18X,4HSYSS)                                                 CORR        96
      VCXK=VCX/1.6876                                             CORR        97
      IF(ITER.EQ.1) XXL=XXLBT                                     CORR        98
      IF(ITER.EQ.1) YYL=YYLBT                                     CORR        99
      WRITE(6,208) ICS,VCXK,TIX,TIY,TEN,PHISD,THORX,TVERT,XXL,YYL,SYISD  CORR   100
  208 FORMAT(I5,10F12.5)                                          CORR       101
      ICS=ICS+1                                                   CABUOY     276
      IF(ICS.GE.150) STOP                                         CORR       102
      GO TO 93                                                    CORR       103
  211 IF(DIR.GE.0.) GO TO 82                                      CORR       104
      DIR=-DIR                                                    CABUOY     280
      TIY=TVERT                                                   CABUOY     281
      TIX=THORX                                                   CABUOY     282
      TEN=SQRT(TIY*TIY+TIX*TIX)                                   CABUOY     283
      PHIS=ATAN2(TIX,-TIY)                                        CABUOY     284
      TNX=TIX-0.5*RHO*CDASX*CCF1*ABS(CCF1)                        CORR       105
      WRITE(6,56) TNX                                             CORR       106
   56 FORMAT(/1X,25HREVISED VALUE OF WIND LO=,F12.4,1X,2HLB)      CORR       107
      GO TO 93                                                    CORR       108
   42 IF(ABS(PHID(1)).LT.360.) GO TO 85                           CABUOY     286
      DO 83 I=1,NCAB                                              CABUOY     287
      PHID(I)=PHIDS(I)                                            CABUOY     288
      TENI(I)=TENIS(I)                                            CABUOY     289
   83 CONTINUE                                                    CABUOY     290
   85 CONTINUE                                                    CABUOY     291
      FNI1=1.                                                     CABUOY     292
      DO 43 I=1,NCAB                                              CABUOY     293
      DC=DCI(I)/12.                                               CABUOY     294
      DRN(I)=0.5*RHO*CDN(I)*DC*FLC(I)                             CABUOY     295
      DRT(I)=0.5*RHO*CDT(I)*DC*FLC(I)                             CABUOY     296
      PHIV(I)=PHID(I)*PI/180.                                     CABUOY     297
      AMK(I)=RHO*AMC*AFAC*PI*DC*(DC/4.)*FLC(I)/FNI1               CABUOY     298
      GM(I)=CM(I)*FLC(I)/FNI1                                     CABUOY     299
      WTC(I)=WC(I)*FLC(I)/FNI1                                    CABUOY     300
   43 CONTINUE                                                    CABUOY     301
      TXS=-TENIS(1)*SIN(PHIDS(1)/RAD)                             CORR       109
      TYS=TENIS(1)*COS(PHIDS(1)/RAD)                              CORR       110
C     COMPUTE X AND Y BASED ON ANGLE AND TENSION AT MIDSEGMENT    CABUOY     302
      DO 48 IC=1,NCAB                                             CABUOY     303
      C21=1./C2(IC)                                               CABUOY     304
      IF(TENI(IC).LE.0.000001) TENI(IC)=0.000001                  CORR       111
      TMTRC=(TENI(IC)-TREF(IC))/C1(IC)                            CABUOY     305
      STR=ABS(TMTRC)**(C21-1.)*TMTRC                              CABUOY     306
      FL=FLC(IC)*(1.+STR)                                         CABUOY     307
      X(IC)=XA-FL*SIN(PHIV(IC))                                   CABUOY     308
      Y(IC)=YA+FL*COS(PHIV(IC))                                   CABUOY     309
      XP(IC)=XPI(IC)$YP(IC)=YPI(IC)                               CABUOY     310
      XA=X(IC)                                                    CABUOY     311
      YA=Y(IC)                                                    CABUOY     312
      XPP(IC)=XP(IC)$YPP(IC)=YP(IC)                               CORR       112
   48 CONTINUE                                                    CABUOY     313
      NDE1=2*NBD                                                  CABUOY     314
      NDE2=NDE1                                                   CABUOY     315
      IF(FSM1.GE.2000.) NDE2=NDE1+3                               CABUOY     316
      NDE=2*NDE2                                                  CABUOY     317
```

```
      TT=0.                                                        CABUOY    318
      WRITE(6,21)                                                  CABUOY    319
   21 FORMAT(1H0,5X,24HCABLE INITIAL CONDITIONS)                   CABUOY    320
      WRITE(6,22)                                                  CABUOY    321
   22 FORMAT(/1X,4HNODE,2X,8HPHI(DEG),3X,7HTEN(LB),4X,5HX(FT),5X,  CABUOY    322
     15HY(FT),4X,8HXV(FT/S),2X,8HYV(FT/S))                         CABUOY    323
      DO 36 I=1,NCAB                                               CABUOY    324
      II=I                                                         CABUOY    325
   36 WRITE(6,23) I,PHIO(I),TENI(I),X(II),Y(II),XPI(I),YPI(I)      CABUOY    326
   23 FORMAT(1X,I3,3X,F10.4,F10.2,2F10.2,2F10.4)                   CABUOY    327
      WRITE(6,24)                                                  CABUOY    328
   24 FORMAT(//5X,16HTIME INFORMATION)                             CABUOY    329
      WRITE(6,86) TINV1,DT1                                        CABUOY    330
   86 FORMAT(/1X,22HINITIAL TIME INTERVAL=,F10.4,1X,3HSEC,3X,      CABUOY    331
     110HTIME STEP=,F10.4,1X,3HSEC)                                CABUOY    332
      WRITE(6,25) TOTT,DT2                                         CABUOY    333
   25 FORMAT(12X,11HTOTAL TIME=,F10.4,1X,3HSEC,3X,10HTIME STEP=,F10.4, CABUOY 334
     11X,3HSEC)                                                    CABUOY    335
      WRITE(6,27)                                                  CABUOY    336
   27 FORMAT(1H1,10X,42HCOMPUTED CABLE SYSTEM MOTIONS AND TENSIONS) CABUOY   337
      WRITE(6,28)                                                  CABUOY    338
   28 FORMAT(//2X,3HNUM,3X,6HT(SEC),2X,7HDT(SEC),3X,5HX(FT),5X,    CABUOY    339
     15HY(FT),3X,8HXP(FT/S),2X,8HYP(FT/S),1X,9HXPP(F/SS),1X,       CABUOY    340
     29HYPP(F/SS),3X,7HTEN(LB),1X,7HFI(DEG),1X,8HFIP(D/S),1X,6HSTRAIN, CABUOY 341
     31X,8HSTP(1/S))                                               CABUOY    342
      ITOP=0                                                       CABUOY    343
      TIN1=TINV1-DELTA                                             CABUOY    344
      TIN2=TINV1+DELTA                                             CABUOY    345
      DT=DT1                                                       CABUOY    346
      FIRST=-1.$START=0.                                           CABUOY    347
      DO 201 KK=1,7500                                             CABUOY    348
      DO 101 I=1,NBD                                               CABUOY    349
      Y0(4*I-3)=X(I)$Y0(4*I-2)=XP(I)                               CABUOY    350
      Y0(4*I-1)=Y(I)$Y0(4*I)=YP(I)                                 CABUOY    351
  101 CONTINUE                                                     CABUOY    352
      IF(NDE2.EQ.NDE1) GO TO 114                                   CABUOY    353
      Y0(NDE-5)=XS$Y0(NDE-4)=XPS$Y0(NDE-3)=ZETI                    CABUOY    354
      Y0(NDE-2)=ZTPI$Y0(NDE-1)=SYI$Y0(NDE)=SYPI                    CABUOY    355
  114 IF(TT.GE.TIN1) DT=DT2                                        CABUOY    356
      IF((TT.GE.TIN1).AND.(TT.LE.TIN2)) START=0.                   CABUOY    357
      CALL KUTMER(NDE,TT,Y0,EPDYN DT,START,HCX,EPR,DYNA)           CORR      113
C     COMPUTE SURFACE WAVE MOTIONS                                 CABUOY    359
      XSW=0.$YSW=0.                                                CABUOY    360
      XSWP=0.$YSWP=0.                                              CABUOY    361
      XSWPP=0.$YSWPP=0.                                            CABUOY    362
      DO 161 IW=1,NSW                                              CABUOY    363
      WXSF=WKSW(IW)*XSI-SIG(IW)*TT+FISW(IW)                        CABUOY    364
      CWXSF=COS(WXSF)$SWXSF=SIN(WXSF)                              CABUOY    365
      XSW=XSW+ASW(IW)*CWXSF                                        CABUOY    366
      YSW=YSW-ASW(IW)*SWXSF                                        CABUOY    367
      XSWP=XSWP+SIG(IW)*ASW(IW)*SWXSF                              CABUOY    368
      YSWP=YSWP+SIG(IW)*ASW(IW)*CWXSF                              CABUOY    369
      XSWPP=XSWPP-SIG(IW)**2*ASW(IW)*CWXSF                         CABUOY    370
      YSWPP=YSWPP+SIG(IW)**2*ASW(IW)*SWXSF                         CABUOY    371
  161 CONTINUE                                                     CABUOY    372
      WRITE(6,162) TT,HCX,XSW,YSW,XSWP,YSWP,XSWPP,YSWPP            CABUOY    373
  162 FORMAT(/1X,4HJAVE,F8.4,F8.6,2F10.2,4F10.4)                   CABUOY    374
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            IF(NUE2.EQ.NOE1) GO TO 121                                          CABUOY     375
            SYO=SYI*180./PI$SYPO=SYPI*180./PI$SYPPD=SYPP*180./PI                CABUOY     376
            WRITE(6,123)  TT,HCX,XSI,ZETI,XPSI,ZTPI,XPDSI,ZETPP,SYO,SYPO,SYPPD  CABUOY     377
        123 FORMAT(1X,4HBUOY,F8.4,F8.6,2F10.2,4F10.4,10X,2F8.2,                 CABUOY     378
           11X,5HSYPP=,F8.2,1X,4HD/SS)                                          CABUOY     379
        121 DELX=X(1)-XS$DELY=Y(1)-YS                                           CABUOY     380
            DXP=XP(1)-XSP$DYP=YP(1)-YSP                                         CABUOY     381
            FLS=SQRT(DELX*DELX+DELY*DELY)                                       CABUOY     382
            FIDS=ATAN2(-DELX,DELY)*180./PI                                      CABUOY     383
            EPS=(FLS-FLC(1))/FLC(1)                                             CABUOY     384
            EPSP=(DELX*DXP+DELY*DYP)/(FLS*FLC(1))                               CABUOY     385
            TENSS=C1(1)*(ABS(EPS))**(C2(1)-1.)*EPS+TREF(1)+CINT(1)*EPSP         CABUOY     386
            IF(TENSS.LE.TMIN) TENSS=TMIN                                        CABUOY     387
            FIPS=((-DXP/FLS)+DELX*(DELX*DXP+DELY*DYP)/FLS**3)/                  CABUOY     388
           1COS(FIDS*PI/180.)                                                   CABUOY     389
            FIPDS=FIPS*180./PI                                                  CABUOY     390
            WRITE(6,125)  TOP,TT,HCX,XS,YS,XSP,YSP,TENSS,FIDS,FIPDS,EPS,EPSP    CABUOY     391
        125 FORMAT(2X,I..,8.4,F8.6,2F10.2,2F10.4,29X,F10.2,2F8.2,2F8.6)         CABUOY     392
            DO 107 I=2,KCAN                                                     CABUOY     393
            DELX=X(I)-X(I-1)$DELY=Y(I)-Y(I-1)                                   CABUOY     394
            DXP=XP(I)-XP(I-1)$DYP=YP(I)-YP(I-1)                                 CABUOY     395
            FLS=SQRT(DELX*DELX+DELY*DELY)                                       CABUOY     396
            FIDS=ATAN2(-DELX,DELY)*180./PI                                      CABUOY     397
            EPS=(FLS-FLC(I))/FLC(I)                                             CABUOY     398
            EPSP=(DELX*DXP+DELY*DYP)/(FLS*FLC(I))                               CABUOY     399
            TENSS=C1(I)*(ABS(EPS))**(C2(I)-1.)*EPS+TREF(I)+CINT(I)*EPSP         CABUOY     400
            IF(TENSS.LE.TMIN) TENSS=TMIN                                        CABUOY     401
            FIPS=((-DXP/FLS)+DELX*(DELX*DXP+DELY*DYP)/FLS**3)/                  CABUOY     402
           1COS(FIDS*PI/180.)                                                   CABUOY     403
            FIPDS=FIPS*180./PI                                                  CABUOY     404
            I1=I-1                                                              CABUOY     405
            WRITE(6,29)  I1,TT,HCX,X(I1),Y(I1),XP(I1),YP(I1),XPP(I1),YPP(I1),   CABUOY     406
           1TENSS,FIDS,FIPDS,EPS,EPSP                                           CABUOY     407
         29 FORMAT(2X,I3,F8.4,F8.6,2F10.2,4F10.4,F10.2,2F8.2,2F8.6)             CABUOY     408
        107 CONTINUE                                                            CABUOY     409
            IF(TT.GE.TOTT) GO TO 1000                                           CABUOY     410
            FIRST=1.0.                                                          CABUOY     411
        201 CONTINUE                                                            CABUOY     412
       1000 CONTINUE                                                            CABUOY     413
            STOP                                                                CABUOY     414
            END                                                                 CABUOY     415
```

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      SUBROUTINE STAT(SR,FIN,DER)                                  CABUOY  416
      COMMON/MS1/DRAGN,DRAGT,WPUL,TRF,TC1,TEX1                     CABUOY  417
      DIMENSION FIN(5),DER(5)                                      CABUOY  418
      IF(FIN(1).LE.0.00000001) FIN(1)=0.00000001                   CABUOY  419
      CALL CUR(FIN(4),CX)                                          CABUOY  420
      CNORM=COS(FIN(2))*CX                                         CABUOY  421
      CTAN=-SIN(FIN(2))*CX                                         CABUOY  422
      STRN=(ABS(FIN(1)-TRF)/TC1)**(TEX1-1.)*((FIN(1)-TRF)/TC1)     CABUOY  423
                                                                   CABUOY  424
   17 DER(5)=1.+STRN                                               CABUOY  425
      G=DRAGT*CTAN*ABS(CTAN)                                       CABUOY  426
      FI=DRAGN*CNORM*ABS(CNORM)                                    CABUOY  427
      DER(1)=-G-COS(FIN(2))*WPUL                                   CABUOY  428
      DER(2)=(-FI-SIN(FIN(2))*WPUL)/(-FIN(1))                      CABUOY  429
      DER(3)=-SIN(FIN(2))*DER(5)                                   CABUOY  430
      DER(4)=COS(FIN(2))*DER(5)                                    CABUOY  431
      RETURN                                                       CABUOY  432
      END
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      SUBROUTINE DYNA(T,FI,DF)                                          CABUOY   433
      DIMENSION DE(106),FI(106)                                         CABUOY   434
      COMMON/MD1/AXSM(20),AYSM(20),FISM(20),WKSM(20),SIG(20),WSM(20),   CABUOY   435
     1FISM(20),NSM                                                      CABUOY   436
      COMMON/MDSP/ASM(20),FRSM(20),NSM,NIRG                             CORR     114
      COMMON/MD3/TMIN,NCAB,NOE2,NOE1,OKUL,CALL,TBYMX                    CORR     115
      COMMON/MD4/C1(50),C2(50),CINT(50),URN(50),DRT(50),AMN(50),GM(50), CABUOY   439
     1MTC(50),TREF(50),FLC(50)                                          CABUOY   440
      COMMON/MBD/RHO,PI,G,CCF1,FSM1,RNX,TXS,TYS,SUBM,RTY,RTX,RHY,YCG,   CABUOY   441
     1BIN,BG,MAS,CDASX,CDASY,XA,YA,XPA,YPA                              CABUOY   442
      COMMON/MDSB/XPPSI,ZETPP,SYPP,XSI,ZETI,SYI,XPSI,ZTPI,SYPI          CABUOY   443
      COMMON/LDS/MBD(50),CDABX(50),CDABY(50),XMBV(50),YMBV(50)          CABUOY   444
      COMMON/MDDK/XMB(50),YMB(52),ZM                                    CABUOY   445
      COMMON/DMS/XS,YS,XSP,YSP,XSPP,YSPP,X(51),Y(51),XP(51),            CABUOY   446
     1YP(51),XPP(51),YPP(51)                                            CABUOY   447
      COMMON/SPAR/PS0,PS1,PS2,QS0(20),QS1(20),RGS0,BVMX,BVMZ            CABUOY   448
      COMMON/SPHER/BVIP,SPF,RGVCG,WVIP,DYM,WVMX,WVMZ,DB                 CABUOY   449
      NOE=2*NOE2$NBD=NCAB-1                                             CABUOY   450
      DO 5 I=1,NOE2                                                     CABUOY   451
    5 DE(2*I-1)=FI(2*I)                                                 CABUOY   452
      DO 6 I=1,NBD                                                      CABUOY   453
      X(I)=FI(4*I-3)$XP(I)=FI(4*I-2)                                    CABUOY   454
      Y(I)=FI(4*I-1)$YP(I)=FI(4*I)                                      CABUOY   455
    6 CONTINUE                                                          CABUOY   456
      IF(FSM1.LE.2000.) GO TO 45                                        CABUOY   457
      XSI=FI(NOE-5)$XPSI=DE(NOE-5)                                      CABUOY   458
      ZETI=FI(NOE-3)$ZTPI=DE(NOE-3)                                     CABUOY   459
      SYI=FI(NOE-1)$SYPI=DE(NOE-1)                                      CABUOY   460
      XS=XSI+RTX-RTY*SYI                                                CORR     116
      XSP=XPSI-RTY*SYPI                                                 CORR     117
      YS=YCG+ZETI+RTX*SYI+RTY                                           CORR     118
      YSP=ZTPI+RTX*SYPI                                                 CORR     119
      GO TO 12                                                          CABUOY   465
   45 XS=0.$YS=SUBM$XSP=0.$YSP=0.                                       CABUOY   466
      DO 11 I=1,NSM                                                     CABUOY   467
      WSTF=-WSM(I)*T+FISM(I)                                            CABUOY   468
      XS=XS+AXSM(I)*COS(WSTF)                                           CABUOY   469
      YS=YS-AYSM(I)*SIN(WSTF)                                           CABUOY   470
      XSP=XSP+WSM(I)*AXSM(I)*SIN(WSTF)                                  CABUOY   471
   11 YSP=YSP+WSM(I)*AYSM(I)*COS(WSTF)                                  CABUOY   472
   12 XA=XS$YA=YS$XAP=XSP$YAP=YSP                                       CABUOY   473
      IC=1                                                              CABUOY   474
      FLN=FLC(IC)                                                       CABUOY   475
      DELX=X(1)-XA                                                      CABUOY   476
      DELY=Y(1)-YA                                                      CABUOY   477
      FIV=ATAN2(-DELX,DELY)                                             CABUOY   478
      DXP=XP(1)-XAP$DYP=YP(1)-YAP                                       CABUOY   479
      CSF=COS(FIV)$SNF=SIN(FIV)                                         CABUOY   480
      EPSB=(DELY/CSF-FLN)/FLN                                           CABUOY   481
      EPPB=(DELX*DXP+DELY*DYP)/(SQRT(DELX**2+DELY**2)*FLN)              CABUOY   482
      TB=C1(1)*ABS(EPSB)**(C2(1)-1.)*EPSB+TREF(1)*CINT(1)*EPPB          CABUOY   483
      IF(TB.LE.TMIN) TB=TMIN                                            CABUOY   484
      TENB=TB$FVB=FIV                                                   CABUOY   485
      IF(ABS(TENB).GE.TBYMX) TENB=TBYMX*TENB/ABS(TENB)                  CORR     123
      DO 41 IC=1,NCAB                                                   CABUOY   486
      GMN=AMN(IC)+GM(IC)                                                CABUOY   487
C     CALCULATE EQUATIONS FOR CORNER ELEMENTS                           CABUOY   488
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SUBROUTINE DYN?      74/74    OPT=0 ROUND=*/ TRACE          FTN 4.6+420        04/19/77  11.49.22       PAGE    2

            IF(IC.GE.NCAB) GO TO 43                                                    CABUOY   489
            CSFA=CSF$SNFA=SNF$TA=TB                                                    CABUOY   490
            FCA=1.0$FCB=1.0                                                            CABUOY   491
            IF(IC.EQ.1) FCA=2.0                                                        CABUOY   492
            IF(IC.EQ.(NCAB-1)) FCB=2.0                                                 CABUOY   493
            IC1=IC+1                                                                   CABUOY   494
            DELX=X(IC1)-X(IC)$DELY=Y(IC1)-Y(IC)                                        CABUOY   495
            FIV=ATAN2(-DELX,DELY)                                                      CABUOY   496
            DXP=XP(IC1)-XP(IC)$DYP=YP(IC1)-YP(IC)                                      CABUOY   497
            CSF=COS(FIV)$SNF=SIN(FIV)                                                  CABUOY   498
            FLN=FLC(IC)                                                                CABUOY   499
            EPSB=(DELY/CSF-FLN)/FLN                                                    CABUOY   500
            EPPB=(DELX*DXP+DELY*DYP)/(SQRT(DELX**2+DELY**2)*FLN)                       CABUOY   501
            TB=C1(IC1)*ABS(EPSB)**(C2(IC1)-1.)*EPSB+TREF(IC1)+                         CABUOY   502
           1CINT(IC1)*EPPB                                                             CABUOY   503
            IF(TB.LE.TMIN)TB=TMIN                                                      CABUOY   504
            TX=+TA*SNFA-TB*SNF                                                         CABUOY   505
            TY=-TA*CSFA+TB*CSF                                                         CABUOY   506
            XHP=0.$YHP=0.                                                              CABUOY   507
            DO 37 IS=1,NSW                                                             CABUOY   508
            UKY=WKSW(IS)*Y(IC)                                                         CABUOY   509
            IF(ABS(UKY).GE.5.) GO TO 38                                                CABUOY   510
            UKXSF=WKSW(IS)*X(IC)-SIG(IS)*T+FISW(IS)                                    CABUOY   511
            XHP=XHP+ASW(IS)*SIG(IS)*EXP(-UKY)*SIN(UKXSF)                               CABUOY   512
         37 YHP=YHP+ASW(IS)*SIG(IS)*EXP(-UKY)*COS(UKXSF)                               CABUOY   513
         38 CALL CUR(Y(IC),CU)                                                         CABUOY   514
            VRX=XHP+CU-XP(IC)                                                          CABUOY   515
            VRY=YHP-YP(IC)                                                             CABUOY   516
            VR=SQRT(VRX*VRX+VRY*VRY)                                                   CABUOY   517
            VRNA=VRX*CSFA+VRY*SNFA                                                     CABUOY   518
            VRNB=VRX*CSF+VRY*SNF                                                       CABUOY   519
            VRTA=-VRX*SNFA+VRY*CSFA                                                    CABUOY   520
            VRTB=-VRX*SNF+VRY*CSF                                                      CABUOY   521
            DNA=0.5*DRN(IC)*VRNA*ABS(VRNA)                                             CABUOY   522
            DNB=0.5*DRN(IC1)*VRNB*ABS(VRNB)                                            CABUOY   523
            DTA=0.5*DRT(IC)*VRTA*ABS(VRTA)                                             CABUOY   524
            DTB=0.5*DRT(IC1)*VRTB*ABS(VRTB)                                            CABUOY   525
            DNX=FCA*DNA*CSFA+FCB*DNB*CSF                                               CABUOY   526
            DNY=FCA*DNA*SNFA+FCB*DNB*SNF                                               CABUOY   527
            DTX=-FCA*DTA*SNFA-FCB*DTB*SNF                                              CABUOY   528
            DTY=FCA*DTA*CSFA+FCB*DTB*CSF                                               CABUOY   529
            IF((COABX(IC).LT.0.).OR.(COABY(IC).LT.0.)) GO TO 61                        CABUOY   530
            COAR=COABX(IC)/(COABY(IC)+0.0000001)                                       CABUOY   531
            IF((COAR.LE.0.5).OR.(COAR.GE.2.)) GO TO 71                                 CABUOY   532
            DBX=0.5*RHO*COABX(IC)*VR*VRX                                               CABUOY   533
            DBY=0.5*RHO*COABY(IC)*VR*VRY                                               CABUOY   534
            GO TO 72                                                                   CABUOY   535
      C     COMPUTE DRAG AND ADDED MASS COEFFICIENTS FOR CIRCULAR DISK                 CABUOY   536
      C     ACCORDING TO REPORT NADC-AE-7120                                           CABUOY   537
         61 IF(COABY(IC).LT.0.) GO TO 65                                               CABUOY   538
            DIAM=SQRT(-4.*COABX(IC)/(1.*PI))                                           CABUOY   539
            IF(ABS(XPP(IC)).LE.0.0000001) XPP(IC)=0.0000001                            CABUOY   540
            V2AD=ABS((XP(IC)*XP(IC))/(XPP(IC)*DIAM))                                   CABUOY   541
            SV2=SQRT(V2AD)                                                             CABUOY   542
            IF(SV2.GE.DKUL) SV2=DKUL$IF(SV2.LE.DKLL) SV2=DKLL                          CABUOY   543
            COABX(IC)=((PI*DIAM**2/4.)*2.2)/SV2                                        CABUOY   544
            XMBV(IC)=XMB(IC)+1.2*SV2*RHO*DIAM**3                                       CABUOY   545
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      GO TO 71                                                          CABUOY   546
   85 DIAM=SQRT(-4.*CDABY(IC)/(1.12*PI))                                CABUOY   547
      IF(ABS(YPP(IC)).LE.0.0000001) YPP(IC)=0.0000001                   CABUOY   548
      V2AD=ABS((YP(IC)*YP(IC))/(YPP(IC)*DIAM))                          CABUOY   549
      SV2=SQRT(V2AD)                                                    CABUOY   550
      IF(SV2.GE.DKUL) SV2=DKUL$IF(SV2.LE.DKLL) SV2=DKLL                 CABUOY   551
      CDABY(IC)=((PI*DIAM**2/4.)*2.2)/SV2                               CABUOY   552
      YMBV(IC)=YMB(IC)+1.2*SV2*RHO*DIAM**3                              CABUOY   553
   71 DBX=0.5*RHO*CDABX(IC)*VRX*ABS(VRX)                                CABUOY   554
      DBY=0.5*RHO*CDABY(IC)*VRY*ABS(VRY)                                CABUOY   555
   72 FX=TX+DNX+DTX+DBX                                                 CABUOY   556
      IF(IC.EQ.NBU) FX=FX+TBH                                           CABUOY   557
      FY=TY+DNY+DTY+DBY+0.5*FCA*WTC(IC)+0.5*FCB*WTC(IC1)+WBO(IC)        CABUOY   558
      FIX=0.5*(FCA*GM(IC)+FCB*GM(IC1)+FCA*AMN(IC)*CSFA*CSFA+            CABUOY   559
     1FCB*AMN(IC1)*CSF*CSF)+XMBV(IC)                                    CABUOY   560
      FIY=0.5*(FCA*GM(IC)+FCB*GM(IC1)+FCA*AMN(IC)*SNFA*SNFA+            CABUOY   561
     1FCB*AMN(IC1)*SNF*SNF)+YMBV(IC)                                    CABUOY   562
      FKK=+0.5*(FCA*AMN(IC)*SNFA*CSFA+FCB*AMN(IC1)*SNF*CSF)             CABUOY   563
      XPP(IC)=(FIY*FX-FKK*FY)/(FIX*FIY-FKK*FKK)                         CABUOY   564
      YPP(IC)=(FIX*FY-FKK*FX)/(FIX*FIY-FKK*FKK)                         CABUOY   565
      DE(4*IC-2)=XPP(IC)$DE(4*IC)=YPP(IC)                               CABUOY   566
   41 CONTINUE                                                          CABUOY   567
   43 CONTINUE                                                          CABUOY   568
      IF(FSM1.GE.2000.) GO TO 51                                        CABUOY   569
      RETURN                                                            CABUOY   570
C     CALCULATE COMMON TERMS FOR SURFACE BUOY                           CABUOY   571
   51 XMP=0.$YMP=0.                                                     CABUOY   572
      DO 52 IS=1,NSW                                                    CABUOY   573
      UKY=WKSW(IS)*SUBM                                                 CABUOY   574
      IF(ABS(UKY).GE.5.) GO TO 52                                       CORR     121
      UKXSF=WKSW(IS)*XSI-SIG(IS)*T+FISW(IS)                             CABUOY   576
      XMP=XMP+ASW(IS)*SIG(IS)*EXP(-UKY)*SIN(UKXSF)                      CABUOY   577
      YMP=YMP+ASW(IS)*SIG(IS)*EXP(-UKY)*COS(UKXSF)                      CORR     122
   52 CONTINUE                                                          CORR     123
   53 VSX=XMP+CUFI-(XPSI-BG*SYPI)                                       CORR     124
      VSY=YMP-ZTPI                                                      CORR     125
      THX=-TENB*SIN(FYB)$THY=TENB*COS(FYB)                              CABUOY   581
      DBX=0.5*RHO*CDASX*VSX*ABS(VSX)                                    CABUOY   582
      FX=DBX+THX+TWX                                                    CABUOY   583
      DBY=0.5*RHO*CDASY*VSY*ABS(VSY)                                    CABUOY   584
      FY=DBY+THY-TYS-RGS0*ZETI                                          CABUOY   585
      FSY=DBX*(-BG)+(-RTY*SYI+RTX)*THY-(RTX*SYI+RTY)                    CORR     126
     1*THX-RWY*TWA                                                      CORR     127
      IF(FSM1.GE.3000.) GO TO 61                                        CABUOY   587
C     CALCULATE DIFFERENTIAL EQUATIONS FOR SPAR BUOY                    CABUOY   588
      PSIC=PSI                                                          CORR     128
      FRKRX=0.$FRKRY=0.$FRKRS=G*PSI*SYI                                 CORR     129
      DO 55 I=1,NSW                                                     CABUOY   590
      SGFI=WKSW(I)*XSI-SIG(I)*T+FISW(I)                                 CABUOY   591
      FRKRX=FRKRX-2.*SIG(I)**2*ASW(I)*COS(SGFI)*QS0(I)                  CABUOY   592
      FRKRS=FRKRS+2.*SIG(I)**2*ASW(I)*COS(SGFI)*QS1(I)                  CABUOY   593
   55 FRKRY=FRKRY-ASW(I)*SIN(SGFI)*(-SIG(I)**2*WVMZ*US0(I)+RGS0)        CORR     130
      DE(NDE-4)=((BIN+PS2)*(FX+FRKRX)+PSIC*(FSY+FRKRS))/                CORR     131
     1(BVMX*(BIN+PS2)-PSIC**2)                                          CORR     132
      DE(NDE)=(BVMX*(FSY+FRKRS)+PSIC*(FX+FRKRX))/(BVMX*(BIN+PS2)-       CORR     133
     1PSIC**2)                                                          CORR     134
      DE(NDE-2)=(FY+FRKRY)/BVMZ                                         CABUOY   597
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      GO TO 64                                                          CABUOY  599
   61 CONTINUE                                                          CABUOY  600
C     CALCULATE DIFFERENTIAL EQUATIONS FOR SPHEROIDAL BUOY              CABUOY  601
      SPC=-SPF                                                          CORR    135
      FRKRX=0.$FRKRY=0.$FRKRS=RGVBU*SYI                                 CORR    136
      DYS=0.                                                            CORR    137
      DO 65 I=1,NSW                                                     CABUOY  605
      SGFI=WKSW(I)*XSI-SIW(I)*T+FISW(I)                                 CABUOY  606
      FRKRX=FRKRX-WVMX*SIG(I)**2*ASW(I)*COS(SGFI)                       CABUOY  607
      FRKRS=FRKRS+(SPC+PSI)*SIG(I)**2*ASW(I)*COS(SGFI)                  CORR    138
   65 FRKRY=FRKRY-ASW(I)*SIN(SGFI)*(-SIG(I)**2*WVMZ+RGSB)               CABUOY  609
      DE(NDE-4)=(BVIP*(FX+FRKRX)+SPC*(FSY+FRKRS-DYS))/                  CORR    139
     $(BVMX*BVIP-SPC**2)                                                CORR    140
      DE(NDE-2)=(FY+FRKRY)/BVMZ                                         CABUOY  612
      DE(NDE)=(BVMX*(FSY+FRKRS-DYS)+SPC*(FX+FRKRX))/(BVMX*BVIP-SPC**2)  CORR    141
   64 XPPSI=DE(NDE-4)$ZETPP=DE(NDE-2)$SYPP=DE(NDE)                      CABUOY  613
      RETURN                                                            CORR    142
      END                                                               CABUOY  616
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SUBROUTINE CUR        74/74    OPT=0 ROUND=*/ TRACE          FTN 4.6+420        04/19/77  11.49.22        PAGE     1

                SUBROUTINE CUR(Y,CU)                                            CABUOY    617
                COMMON/MCU/YY(10),CCF(10),NCUR,FIRST,VCX                        CABUOY    618
                IF(FIRST.LT.0.0) I=1                                            CABUOY    619
                IF(Y.LT.0.) GO TO 80                                            CABUOY    620
                IF(Y.GT.YY(NCUR)) GO TO 90                                      CABUOY    621
                IF((Y.GE.YY(I)).AND.(Y.LE.YY(I+1))) GO TO 30                    CABUOY    622
                IF((Y.GE.YY(I-1)).AND.(Y.LE.YY(I))) GO TO 40                    CABUOY    623
                IF((Y.GE.YY(I+1)).AND.(Y.LE.YY(I+2))) GO TO 50                  CABUOY    624
             60 I=1                                                             CABUOY    625
             70 IF(Y.LE.YY(I+1)) GO TO 30                                       CABUOY    626
                I=I+1                                                           CABUOY    627
                GO TO 70                                                        CABUOY    628
             30 CU=CCF(I)+((CCF(I+1)-CCF(I))/(YY(I+1)-YY(I)))*(Y-YY(I))         CABUOY    629
               1-VCX                                                            CABUOY    630
                RETURN                                                          CABUOY    631
             40 I=I-1                                                           CABUOY    632
                GO TO 30                                                        CABUOY    633
             50 I=I+1                                                           CABUOY    634
                GO TO 30                                                        CABUOY    635
             80 CU=CCF(1)-VCX                                                   CABUOY    636
                RETURN                                                          CABUOY    637
             90 CU=CCF(NCUR)-VCX                                                CABUOY    638
                RETURN                                                          CABUOY    639
                END                                                             CABUOY    640
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SUBROUTINE SPECT       74/74    OPT=0 ROUND=*/ TRACE            FTN 4.6+428        04/19/77  11.49.22       PAGE     1

              SUBROUTINE SPECT                                                 CABUOY     641
              COMMON/MOSP/ASW(20),FRSW(20),NSW,MTRC                            CORR       143
              G=32.2$PI=3.1415926                                              CABUOY     643
              FLL=FRSW(1)                                                      CABUOY     644
              FUL=FRSW(2)                                                      CABUOY     645
              FNSW=NSW                                                         CABUOY     646
              DELTAW=2.*PI*(FUL-FLL)/FNSW                                      CABUOY     647
              WP=2.*PI*FLL                                                     CABUOY     648
              IF(ASW(1).GE.2000.) GO TO 20                                     CABUOY     649
C       PIERSON-MOSKOWITZ FREQUENCY SPECTRUM                                   CABUOY     650
           10 HSG=ASW(1)-1000.                                                 CABUOY     651
              A=0.0081*G*G$B=33.56/(HSG*HSG)                                   CABUOY     652
              DO 11 I=1,NSW                                                    CABUOY     653
              FI=I                                                             CABUOY     654
              WW=WP+DELTAW                                                     CABUOY     655
              WM=0.5*(WP+WW)                                                   CABUOY     656
              WP=WW                                                            CABUOY     657
              FRSW(I)=WM/(2.*PI)                                               CABUOY     658
              SSW=A*EXP(-B/WM**4)/WM**5                                        CABUOY     659
              ASW(I)=SQRT(SSW*DELTAW)                                          CABUOY     660
           11 CONTINUE                                                         CABUOY     661
              RETURN                                                           CABUOY     662
C       COMPUTE HERE OTHER FREQUENCY SPECTRA                                   CABUOY     663
           20 CONTINUE                                                         CABUOY     664
              END                                                              CABUOY     665
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      SUBROUTINE BUOY                                                    CABUOY   666
      COMMON/MBO/RHO,PI,G,CCF1,FSM1,TMX,TXS,TYS,SUBH,RTY,RTX,RMY,YCG,    CABUOY   667
     1BIN,BG,WAS,CDASX,CDASY,XA,YA,XPA,YPA                               CABUOY   668
      COMMON/MDSB/XPPSI,ZETPP,SYPP,XSI,ZETI,SYI,XPSI,ZTPI,SYPI           CABUOY   669
      COMMON/SPAR/PS0,PS1,PS2,QS0(20),QS1(20),RGS0,BVMX,BVMZ             CABUOY   670
      COMMON/MD1/AXSM(20),AYSM(20),FISM(20),WKSM(20),SIG(20),WSM(20),    CABUOY   671
     1FISM(20),NSM                                                       CABUOY   672
      COMMON/MDSP/ASM(20),FRSM(20),NSM,MTRC                              CORR     144
      COMMON/SPHER/BVIP,SPF,RGVBG,WVIP,DYM,WVMX,WVMZ,BB                  CABUOY   674
      DIMENSION QN0(20),QN1(20)                                          CABUOY   675
      COMMON/MIT/PHISL,XXL,YYL,TTL,VMX,VMN,BCYI,ITER,ICS,WBOT,ORGBTH,TIY CORR     145
     1,SYISU                                                             CORR     146
      DIMENSION HM(20),FS(20),FM(20),FP(20),FPS(20)                      CORR     147
      IF(ICS.GE.2) GO TO 31                                              CORR     148
      READ(5,1) CDASY,WAS,RMY,RTX,RTY,YCG,BIN                            CABUOY   676
      READ(5,1) XSI,ZETI,SYOI,XPSI,ZTPI,SYPOI                            CABUOY   677
      IF(MTRC.LE.0) GO TO 211                                            CORR     149
C     CONVERT METRIC INPUT TO ENGLISH UNITS                              CORR     150
      CDASY=3.281*3.281*CDASY$WAS=WAS/4.452$RMY=3.281*RMY                CORR     151
      RTX=3.281*RTX$RTY=3.281*RTY$YCG=3.281*YCG$BIN=0.7370*BIN           CORR     152
      XSI=3.281*XSI$ZETI=3.281*ZETI$XPSI=3.281*XPSI$ZTPI=3.281*ZTPI      CORR     153
  211 CONTINUE                                                           CORR     154
    1 FORMAT(8F10.4)                                                     CABUOY   678
      SYI=SYOI*PI/180.                                                   CABUOY   679
      SYPI=SYPOI*PI/180.                                                 CABUOY   680
      WRITE(6,3)                                                         CABUOY   681
    3 FORMAT(/5X,23HSURFACE BUOY PARAMETERS)                             CABUOY   682
      WRITE(6,4)                                                         CABUOY   683
    4 FORMAT(/1X,10HCDAY(FTSQ),2X,6HWT(LB),4X,7HRMY(FT),3X,7HRTX(FT),    CABUOY   684
     13X,7HRTY(FT),2X,7HYCG(FT),2X,10HIN(SLFTSQ),2X,6HXI(FT),2X,         CABUOY   685
     29HZETAI(FT),2X,8HSYI(DEG),1X,8HXVI(F/S),1X,9HZTVI(F/S),            CABUOY   686
     12X,9HSYVI(D/S))                                                    CABUOY   687
      WRITE(6,5) CDASY,WAS,RMY,RTX,RTY,YCG,BIN,XSI,ZETI,SYOI,XPSI,       CABUOY   688
     1ZTPI,SYPOI                                                         CABUOY   689
    5 FORMAT(13F10.4)                                                    CABUOY   690
      BMS=WAS/G                                                          CABUOY   691
   31 TYST=TYS+WAS                                                       CORR     155
      IF(FSM1.GE.3000.) GO TO 101                                        CABUOY   693
C     COMPUTE COEFFICIENTS FOR SPAR BUOY                                 CABUOY   694
      BVMX=2.*BMS+TYS/G                                                  CABUOY   695
      BVMZ=BMS+(4.*RHO/3.)*((BMS+TYS/G)/(RHO*PI*AYSM(NSM)))**1.5         CABUOY   696
      DO 11 I=1,NSM                                                      CABUOY   697
      QN0(I)=0.                                                          CABUOY   698
   11 QN1(I)=0.                                                          CABUOY   699
      PN0=0.$PN1=0.$PN2=0.                                               CABUOY   700
      NSM2=NSM-2                                                         CABUOY   701
      DO 2 IS=1,NSM2,2                                                   CABUOY   702
      H=AYSM(IS+1)-AYSM(IS)                                              CABUOY   703
      ALFA=(AYSM(IS+2)-AYSM(IS+1))/H                                     CABUOY   704
      FAC=H*(ALFA+1.)/(6.*ALFA)                                          CABUOY   705
      ALP2=2.*ALFA-1.$ALP1=(ALFA+1.)**2$ALP=ALFA*(2.-ALFA)               CABUOY   706
      S2=AXSM(IS+2)$S1=AXSM(IS+1)$S=AXSM(IS)                             CABUOY   707
      Y2=AYSM(IS+2)$Y1=AYSM(IS+1)$Y=AYSM(IS)                             CABUOY   708
      Y2G=Y2-YCG$Y1G=Y1-YCG$YGG=Y-YCG                                    CABUOY   709
      PN0=PN0+FAC*(ALP2*S2+ALP1*S1+ALP*S)                                CABUOY   710
      PN1=PN1+FAC*(ALP2*Y2G*S2+ALP1*Y1G*S1+ALP*YGG*S)                    CABUOY   711
      PN2=PN2+FAC*(ALP2*Y2G**2*S2+ALP1*Y1G**2*S1+ALP*YGG**2*S)           CABUOY   712
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      DO 14 IN=1,NSH                                               CABUOY   713
      YK=-Y*WKSH(IN)                                               CABUOY   714
      YK1=-Y1*WKSH(IN)                                             CABUOY   715
      YK2=-Y2*WKSH(IN)                                             CABUOY   716
      EKY=EXP(YK)$EKY1=EXP(YK1)$EKY2=EXP(YK2)                      CABUOY   717
      QN0(IN)=QN0(IN)+FAC*(ALP2*EKY2*S2+ALP1*EKY1*S1+ALP*EKY*S)    CABUOY   718
      QN1(IN)=QN1(IN)+FAC*(ALP2*Y2G*EKY2*S2+ALP1*Y1G*EKY1*S1+      CABUOY   719
     1ALP*YGG*EKY*S)                                               CABUOY   720
   14 CONTINUE                                                     CABUOY   721
    2 CONTINUE                                                     CABUOY   722
      FACC=TYST/(RHO*G*PN0)                                        CABUOY   723
      PS0=FACC*PN0*RHO$PS1=FACC*PN1*RHO$PS2=FACC*PN2*RHO           CABUOY   724
      DO 6 I=1,NSH                                                 CABUOY   725
      QS0(I)=FACC*QN0(I)*RHO                                       CABUOY   726
    6 QS1(I)=FACC*QN1(I)*RHO                                       CABUOY   727
      RGS0=RHO*G*AKSH(1)                                           CABUOY   728
      YCB=PS1/PS0                                                  CABUOY   729
      BG=YCB                                                       CABUOY   730
      WVMZ=1.+(WVMZ-BRS)/PS0                                       CORR     156
      IF((ITER.GE.1).AND.(ICS.GE.2)) GO TO 401                     CORR     157
   21 WRITE(6,22)                                                  CABUOY   731
   22 FORMAT(/5X,23HCONSTANTS FOR SPAR BUOY)                       CABUOY   732
      WRITE(6,26) FACC                                             CABUOY   733
   26 FORMAT(1X,20HINITIAL RATIO T /P0=,F10.5)                     CABUOY   734
      WRITE(6,23) PS0,PS1,PS2                                      CABUOY   735
   23 FORMAT(1X,3HP0=,F10.5,5X,3HP1=,F10.5,5X,3HP2=,F10.5)         CABUOY   736
      WRITE(6,24) (QS0(I),I=1,NSH)                                 CABUOY   737
      WRITE(6,25) (QS1(I),I=1,NSH)                                 CABUOY   738
   24 FORMAT(1X,3HQ0=,12F10.5/4X,12F10.5)                          CABUOY   739
   25 FORMAT(1X,3HQ1=,12F10.5/4X,12F10.5)                          CABUOY   740
      WRITE(6,29) WVMZ,RGS0                                        CORR     158
   29 FORMAT(1X,5HWVMZ=,F10.5,5X,5HRGS0=,F10.5)                    CORR     159
      GO TO 401                                                    CABUOY   741
  101 CONTINUE                                                     CABUOY   742
C     COMPUTE COEFFICIENTS FOR PROLATE OR OBLATE SPHEROID          CABUOY   743
      DFT=AYSH(1)$BB=AKSH(1)                                       CABUOY   744
      A=BB$HA=DFT/A                                                CORR     160
      IF(HA.GT.0.1) GO TO 141                                      CORR     161
      FKS=0.0748*HA/0.1                                            CORR     162
      FKM=12.84*0.1/HA                                             CORR     163
      FKP=1.27*0.1/HA                                              CORR     164
      FKPS=0.3                                                     CORR     165
      GO TO 121                                                    CORR     166
  141 IF(HA.GT.10.) GO TO 161                                      CORR     167
      HH(1)=0.1$HH(2)=0.2$HH(3)=0.3$HH(4)=0.5                      CORR     168
      HH(5)=0.7$HH(6)=0.9$HH(7)=1.$HH(8)=1.5                       CORR     169
      HH(9)=2.$HH(10)=3.$HH(11)=5.$HH(12)=7.0                      CORR     170
      HH(13)=10.                                                   CORR     171
      FS(1)=0.0748$FS(2)=0.143$FS(3)=0.204$FS(4)=0.31              CORR     172
      FS(5)=0.397$FS(6)=0.469$FS(7)=0.50$FS(8)=0.622               CORR     173
      FS(9)=0.784$FS(10)=0.884$FS(11)=0.894$FS(12)=0.933           CORR     174
      FS(13)=0.96                                                  CORR     175
      FM(1)=12.84$FM(2)=5.84$FM(3)=3.572$FM(4)=2.085               CORR     176
      FM(5)=1.323$FM(6)=0.968$FM(7)=0.836$FM(8)=0.484              CORR     177
      FM(9)=0.323$FM(10)=0.18$FM(11)=0.082$FM(12)=0.049            CORR     178
      FM(13)=0.020                                                 CORR     179
      FP(1)=1.27$FP(2)=0.555$FP(3)=0.312$FP(4)=0.117               CORR     180
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      FP(5)=0.035$FP(6)=0.0038$FP(7)=0.$FP(8)=0.0731                    CORR      181
      FP(9)=0.272$FP(10)=0.9938$FP(11)=3.65$FP(12)=0.20                 CORR      182
      FP(13)=20.0                                                       CORR      183
      FPS(1)=0.3$FPS(2)=0.264$FPS(3)=0.237$FPS(4)=0.177                 CORR      184
      FPS(5)=0.11$FPS(6)=0.0039$FPS(7)=0.$FPS(8)=-0.191                 CORR      185
      FPS(9)=-0.391$FPS(10)=-0.780$FPS(11)=-1.565$FPS(12)=-2.30         CORR      186
      FPS(13)=-3.75                                                     CORR      187
      I=1                                                               CORR      188
  147 IF(HA.LE.HH(I+1)) GO TO 143                                       CORR      189
      I=I+1                                                             CORR      190
      GO TO 147                                                         CORR      191
  143 CONTINUE                                                          CORR      192
      FKS=FS(I)+((FS(I+1)-FS(I))/(HH(I+1)-HH(I)))*(HA-HH(I))            CORR      193
      FKH=FH(I)+((FH(I+1)-FH(I))/(HH(I+1)-HH(I)))*(HA-HH(I))            CORR      194
      FKP=FP(I)+((FP(I+1)-FP(I))/(HH(I+1)-HH(I)))*(HA-HH(I))            CORR      195
      FKPS=FPS(I)+((FPS(I+1)-FPS(I))/(HH(I+1)-HH(I)))*(HA-HH(I))        CORR      196
      GO TO 121                                                         CORR      197
C   USE SPAR BUOY STRIP THEORY FOR H/A.GT.10                            CORR      198
  161 CONTINUE                                                          CORR      199
      FKS=1.-.84*EXP(-0.09944*(HA-10.))                                 CORR      200
      FKH=0.020                                                         CORR      201
      FKP=HA**2/5.                                                      CORR      202
      FKPS=-3.*HA/8.                                                    CORR      203
      GO TO 121                                                         CORR      204
  121 VOL=2.*PI*DFT*BB*BB/3.                                            CABUOY    764
      VM1=PI*BB*BB*(DFT*DFT/4.-2.*YCG*DFT/3.)                           CABUOY    765
      FACC=TYST/(RHO*G*VOL)                                             CABUOY    766
      VOL=FACC*VOL$VM1=FACC*VM1                                         CABUOY    767
      BG=VM1/VOL                                                        CABUOY    768
      COUPL=FKPS*A+YCG*FKS                                              CORR      205
      API=FKP*A*A+2.*YCG*FKPS*A+YCG**2*FKS                              CORR      206
      BVMX=BMS+FKS*RHO*VOL                                              CORR      207
      BVMZ=BMS+FKH*RHO*VOL                                              CORR      208
      BVIP=BIN+API*RHO*VOL                                              CORR      209
      HVMX=(1.+FKS)*RHO*VOL                                             CORR      210
      HVMZ=(1.+FKH)*RHO*VOL                                             CORR      211
      SPF=COUPL*RHO*VOL                                                 CORR      212
      RGVBG=RHO*G*VOL*BG                                                CORR      213
      RGSB=RHO*G*PI*BB*BB                                               CORR      214
      PS1=RHO*VM1                                                       CORR      215
      IF((ITER.GE.1).AND.(ICS.GE.2)) GO TO 401                          CORR      216
      WRITE(6,131)                                                      CABUOY    785
  131 FORMAT(/5X,29HCONSTANTS FOR SPHEROIDAL BUOY)                      CABUOY    786
      WRITE(6,26) FACC                                                  CABUOY    787
      WRITE(6,132)                                                      CABUOY    788
  132 FORMAT(1X,9HDRAFT(FT),3X,5HB(FT),4X,7HDRAFT/B,2X,                 CABUOY    789
     19HVOL(CUFT),1X,10HVOL*Y(FT4),4X,3HFKS,7X,3HFKH,7X,3HFKP,6X,       CORR      217
     14HFKPS,6X,4HRGSB)                                                 CORR      218
      WRITE(6,133) DFT,BB,HA,VOL,VM1,FKS,FKH,FKP,FKPS,RGSB              CORR      219
  133 FORMAT(10F10.4)                                                   CORR      220
  401 CONTINUE                                                          CABUOY    794
      YSI=YCG+ZETI                                                      CABUOY    795
C   CALCULATE STATIC VALUE OF SY                                        CABUOY    796
      OBM=(-THX-TXS)*(-BG)                                              CABUOY    797
      SYIN=-OBM-RTX*TYS+RTY*TXS+RMY*THX                                 CABUOY    798
      SYID=G*PS1-RTY*TYS-RTX*TXS                                        CORR      221
      SYIS=(SYIN/SYID)                                                  CORR      222
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SUBROUTINE BUOY        74/74    OPT=0 ROUND=*/ TRACE             FTN 4.6+420         04/19/77  11.49.22          PAGE      4

                 SYISD=SYIS*180./PI                                                  CABUOY     800
                 IF((ITER.GE.1).AND.(ICS.GE.2)) GO TO 404                            CORR       223
                 WRITE(6,28) BG                                                      CABUOY     801
              28 FORMAT(5X,8HYCB-YCG=,F10.4,1X,2HFT)                                 CABUOY     802
                 WRI E(6,27) SYISD                                                   CABUOY     803
              27 FORMAT(5X,11HSTEADY SYI=,F10.4,1X,3HDEG)                            CABUOY     804
             404 I (SYUI.GE.360.) SYI=SYIS                                           CORR       224
           C     COMPUTE YA,XA,XPA,YPA                                               CABUOY     806
                 XA=XSI+RTX-RTY*SYI                                                  CORR       225
                 YA=YSI+RTX*SYI+RTY                                                  CORR       226
                 XPA=XPSI-RTY*SYPI                                                   CORR       227
                 YPA=ZTPI+RTX*SYPI                                                   CORR       228
                 RETURN                                                              CABUOY     811
                 END                                                                 CABUOY     812
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                SUBROUTINE ITERA                                            CABUOY    013
                COMMON/MCU/ YY(10),CCF(10),MCUR,FIRST,VCX                   CABUOY    014
                COMMON/MIT/PHISL,XXL,YYL,TTL,VMX,VMN,BCYI,ITER,ICS,WBOT,ORGBTH,TIY CORR 229
               1,SYISO                                                      CORR      230
                IF(ITER.LE.0) RETURN                                        CABUOY    016
                GO TO (101,201,301) ITER                                    CABUOY    017
          C   PERFORM ITERATIONS FOR FREE FLOATING CASE                     CORR      231
            101 IF(ICS.GE.2) GO TO 111                                      CABUOY    018
            102 VCX=0.5*(VMX+VMN)                                           CABUOY    019
                TIY=-BCYI                                                   CABUOY    020
                TIYMN=-BCYI                                                 CABUOY    021
                TIYMX=0.                                                    CABUOY    022
                DHFAC=0.7                                                   CORR      232
                TMAX=1.0$TMIN=1.0                                           CORR      233
                PRERV=1000.                                                 CABUOY    024
                RETURN                                                      CABUOY    025
            111 ERX=-TTL*SIN(PHISL)                                         CORR      234
                ERY=TTL*COS(PHISL)                                          CORR      235
                ERR=SQRT(ERX*ERX+ERY*ERY)                                   CABUOY    026
                RATIO2=ABS(ERY/WBOT)                                        CABUOY    029
                WBT1=0.01*ABS(WBOT)                                         CORR      236
                IF(ABS(ORGBTH).LE.WBT1) ORGBTH=WBT1                         CORR      237
                IF(ABS(ORGBTH).GE.ABS(WBOT)) ORGBTH=ABS(WBOT)               CORR      238
                RATIO3=ABS(ERX/ORGBTH)                                      CABUOY    030
                VTEMP=VCX                                                   CABUOY    031
                TYTEMP=TIY                                                  CABUOY    032
                IF((RATIO2.LE.0.01).AND.(RATIO3.LE.0.01)) GO TO 501         CORR      239
                IF(RATIO3.LE.0.01) GO TO 121                                CORR      240
                IF(ERX.LT.0.) GO TO 115                                     CABUOY    035
            112 VCX=0.5*(VCX+VMN)                                           CABUOY    036
                VMX=VTEMP                                                   CABUOY    037
                RETURN                                                      CABUOY    038
            115 VCX=0.5*(VCX+VMX)                                           CABUOY    039
                VMN=VTEMP                                                   CABUOY    040
                RETURN                                                      CABUOY    041
            121 IF((-ERY/PRERV).GT.0.5) DHFAC=0.5*DHFAC                     CABUOY    042
                IF((ERY/PRERV).GT.0.7) DHFAC=1.5*DHFAC                      CABUOY    043
                PRERV=ERY                                                   CABUOY    044
                TIY=TYTEMP+DHFAC*ERY                                        CABUOY    045
                IF(ERY.LT.0.) GO TO 125                                     CABUOY    046
            122 IF(TIY.GE.TIYMX) TIY=0.5*(TYTEMP+TIYMX)                     CORR      241
                TMIN=TIY/TYTEMP                                             CABUOY    048
                TMAX=TYTEMP/TIY                                             CABUOY    049
                TIYMN=TYTEMP                                                CORR      242
                GO TO 127                                                   CABUOY    051
            125 IF(TIY.LE.TIYMN) TIY=0.5*(TYTEMP+TIYMN)                     CORR      243
                TMAX=TIY/TYTEMP                                             CABUOY    053
                TMIN=TYTEMP/TIY                                             CABUOY    054
                TIYMX=TYTEMP                                                CORR      244
            127 VMX=(TMAX+0.05)*VCX                                         CABUOY    056
                VMN=(TMIN-0.05)*VCX                                         CABUOY    057
                WRITE(6,191)                                                CORR      245
            191 FORMAT(/)                                                   CORR      246
                RETURN                                                      CABUOY    058
            201 CONTINUE                                                    CABUOY    059
          C   PERFORM ITERATIONS FOR MOORED CASE                            CORR      247
                IF(ICS.GE.2) GO TO 211                                      CORR      248
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SUBROUTINE ITERA       74/74    OPT=0 ROUND=*/ TRACE            FTN 4.6+420         04/19/77  11.49.22       PAGE    2

             TIY=-2.*BCYI                                                          CORR        249
             TIYMN=-100.*BCYI                                                      CORR        250
             TIYMX=0.                                                              CORR        251
             RETURN                                                                CORR        252
         211 ERY=YYL-YY(NCUR)                                                      CORR        253
             ABSERY=ABS(ERY)                                                       CORR        254
             IF(ABSERY.LT.0.01) GO TO 501                                          CORR        255
             TYTEMP=TIY                                                            CORR        2[illegible]
             IF(ERY) 212,212,214                                                   CORR        257
         212 TIY=0.5*(TYTEMP+TIYMN)                                                CORR        258
             TIYMX=TYTEMP                                                          CORR        259
             RETURN                                                                CORR        260
         214 TIY=0.5*(TYTEMP+TIYMX)                                                CORR        261
             TIYMN=TYTEMP                                                          CORR        262
             RETURN                                                                CORR        263
         301 CONTINUE                                                              CABUOY      860
         501 ITER=0                                                                CABUOY      861
             RETURN                                                                CABUOY      862
             END                                                                   CABUOY      863
```

```
          SUBROUTINE KUTMER(N,T,Y0,EPS,H,FIRST,HCX,A,DAUX)                     CABUOY    864
C          KUTMER ROUTINE REVISED FOR IVODE    JAN 30,1964                     CABUOY    865
          DIMENSION Y0(106),Y1(106),Y2(105),F0(106),F1(106),F2(106)            CABUOY    866
          IF(FIRST) 20,10,20                                                   CABUOY    867
       10 HC=H                                                                 CABUOY    868
          IPLOC=1                                                              CABUOY    869
          FIRST=1.                                                             CABUOY    870
       20 LOC=0                                                                CABUOY    871
            HCX=HC                                                             CABUOY    872
       30 CALL DAUX (T,Y0,F0)                                                  CABUOY    873
       39 DO 40 I=1,N                                                          CABUOY    874
       40 Y1(I)=Y0(I)+(HC/3.)*F0(I)                                            CABUOY    875
          CALL DAUX (T+HC/3.,Y1,F1)                                            CABUOY    876
          DO 50 I=1,N                                                          CABUOY    877
       50 Y1(I)=Y0(I)+(HC/6.)*F0(I)+(HC/6.)*F1(I)                              CABUOY    878
          CALL DAUX (T+HC/3.,Y1,F1)                                            CABUOY    879
          DO 60 I=1,N                                                          CABUOY    880
       60 Y1(I)=Y0(I)+HC/8.*F0(I)+.375*HC*F1(I)                                CABUOY    881
          CALL DAUX (T+HC/2.,Y1,F2)                                            CABUOY    882
          DO 70 I=1,N                                                          CABUOY    883
       70 Y1(I)=Y0(I)+HC/2.*F0(I)-1.5*HC*F1(I)+2.*HC*F2(I)                     CABUOY    884
          CALL DAUX (T+HC,Y1,F1)                                               CABUOY    885
          DO 80 I=1,N                                                          CABUOY    886
       80 Y2(I)=Y0(I)+HC/6.*F0(I)+.66666667*HC*F2(I)+(HC/6.)*F1(I)             CABUOY    887
          INC=0                                                                CABUOY    888
          DO 110 I=1,N                                                         CABUOY    889
            ZZZ=ABS (Y1(I))-A                                                  CABUOY    890
            IF(ZZZ) 85,87,87                                                   CABUOY    891
       85  ERROR = ABS(.2*(Y1(I)-Y2(I)) )                                      CABUOY    892
            IF(ERROR-A) 100,100,90                                             CABUOY    893
       87 ERROR=ABS (.2-.2*Y2(I)/Y1(I))                                        CABUOY    894
          IF(ERROR-EPS) 100,100,90                                             CABUOY    895
       90 CONTINUE                                                             CABUOY    896
          KYSCIE=24                                                            CABUOY    897
          CZATR=2.**KYSCIE                                                     CABUOY    898
          XX= CZATR*ABS(HC)-ABS(H)                                             CABUOY    899
          IF (XX) 91,95,95                                                     CABUOY    900
       91  WRITE(6,92)   T,ERROR,I                                             CABUOY    901
       92 FORMAT(21H RELATIVE ERROR AT X= 1P1E12.3,3H IS F10.6/  6H  I=  ,I4)  CABUOY    902
            FIRST = 2.                                                         CABUOY    903
            RETURN                                                             CABUOY    904
       95 HC=HC/2.                                                             CABUOY    905
          IPLOC=2 *IPLOC                                                       CABUOY    906
          LOC=2 *LOC                                                           CABUOY    907
            HCX=HC                                                             CABUOY    908
          GO TO 30                                                             CABUOY    909
      100 IF(ERROR*64.-EPS)110,110,101                                         CABUOY    910
      101 INC=1                                                                CABUOY    911
      110 CONTINUE                                                             CABUOY    912
      111 T=T+HC                                                               CABUOY    913
          DO 112 I=1,N                                                         CABUOY    914
      112 Y0(I)=Y2(I)                                                          CABUOY    915
          LOC=LOC+1                                                            CABUOY    916
           IF(LOC-IPLOC)120,210,210                                            CABUOY    917
      120 IF(INC)210,130,210                                                   CABUOY    918
      130 IF(LOC-(LOC/2)*2)210,140,210                                         CABUOY    919
      140 IF(IPLOC-1)210,210,200                                               CABUOY    920
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SUBROUTINE KUTMER      74/74    OPT=0 20 ·''-*/ TRACE          FTN 4.6+420       04/19/77  11.49.22       PAGE     2

              30 HC=2.*HC                                                          CABUOY    921
                 LOC=LOC/2                                                         CABUOY    922
                 IPLOC=IPLOC/2                                                     CABUOY    923
             210 IF(IPLOC-LOC)30,220,30                                            CABUOY    924
             220 RETURN                                                            CABUOY    925
                 END                                                               CABUOY    926
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